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MANUAL

FOR

WATER WORKS OPERATORS

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EDITOR'S PREFACE

An important outgrowth of the Texas Water Works Short School has been the procedure of voluntary licensing or certification of water works operators. Since the licensing is based upon the taking of examinations a need was soon apparent for a manual that would give in small compass and at no great cost the information required for passing the examinations covering the various grades of licenses. This book is an attempt to meet that need and no further claim is made for it.

Some explanation as to the method of preparing the book should be given. The Manual Committee chose the chapter authors and indicated to them their respective fields. The Committee then read the contributions, assembled them in mimeographed form, and distributed them for criticism. Many of the chapters were read at the 19th Annual Short School in February 1937 and discussions and suggestions for improvements were invited. At this stage the material, including the criticisms and suggestions, was turned over to the editor for final integration into finished form.

The water works men of Texas are greatly indebted to the members of the Manual Committee for their efforts in making the Manual possible and especially to those who carefully read and made constructive comments on the whole manuscript. Of the chapter authors, John B. Hawley and D. W. Robinson performed similar service. Other gentlemen identified with the water works industry also generously gave of their time in reading and criticising all or a part of the manuscript.

E. W. Steel

College Station, Texas,
Jan. 12, 1938

Chapter I

WATER AND ITS IMPURITIES

By E. W. Steel

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Pure water does not exist in nature. Even rain water contains some dust and gases when it reaches the ground. The common impurities include: those in solution—gases, minerals or salts, and organic matter; those in suspension—silt, sand, clay, and living organisms, as algae and bacteria. Some of the impurities are of no consequence, except when they are present in large amounts. Others are of such importance (these include the disease bacteria) that they must be removed or kept out of the water by all possible precautions. *Water treatment* is the removal of those impurities whose presence makes the water undesirable for domestic, industrial or other use. A *safe water* is one that will not cause disease or other harm to those persons who drink it. This term should be used by water works men rather than the term ''pure water.'' A *potable water* is one that is suitable for domestic use and therefore safe to drink, in addition to being usable for cooking, washing and watering stock. A *polluted* water contains organic matter or wastes to the extent that it is not fit for domestic use. A *contaminated water* contains germs of disease. A water polluted with sewage will undoubtedly be contaminated. Fig. 1 shows in tabular form the common impurities of water and their effects.

Water and Disease.—The common water-borne diseases in the United States are *typhoid fever, paratyphoid fever, bacillary dysentery* and *amebic dysentery.* The organisms responsible for these diseases leave infected persons in the bowel or urinary discharges. They may appear in drinking water through the following chain of circumstances: (1) poor methods of disposing of sewage or excreta; (2) lack of safeguards around the water supply, the water plant, and the distribution system; (3) no treatment or insufficient treatment of the water before it is delivered to the consumer. The water works man should accept full responsibility regarding waterborne disease, apply all possible precautions and welcome investigations, but when epidemics occur he should see that other possible sources than the water are also checked. He should recognize, therefore, that the diseases mentioned are frequently carried by foods, particularly milk, which have been contaminated by infected food handlers or by flies.

Suspended Impurities	Bacteria			*Some cause disease*	
	Algae, protozoa			*odor, color, turbidity*	
	Silt			*murkiness or turbidity*	
Dissolved Impurities	Salts *	Calcium and Magnesium	bicarbonate	*alkalinity, hardness*	✓
			carbonate	*alkalinity, hardness*	✓
			sulfate	*hardness*	✓
			chloride	*hardness, corrosive to boilers*	✓
		Sodium	bicarbonate	*alkalinity, has softening effect*	
			carbonate	*alkalinity, has softening effect*	
			sulfate	*foaming in steam boilers*	
			fluoride	*mottled enamel of teeth*	
			chloride	*salty taste*	✓
	Iron oxide			*taste, red water, corrosive to metals, hardness*	
	Manganese			*black or brown water*	
	Vegetable dyes			*color, acidity*	
	Gases	Oxygen		*corrosive to metals*	
		Carbon dioxide		*corrosive to metals, acidity*	
		Hydrogen sulfide		*rotten-egg odor, acidity, corrosive*	
		Nitrogen		*no effect*	

* Salts cause tastes if present in large amounts.

FIG. 1. Common Impurities of Water. Their effects are indicated by *italics.*

Mottled enamel is an incurable condition of the teeth characterized by unsightly brown stains. It is caused by presence in drinking water of more than about 1 part per million of fluorides. The damage occurs only if the water is drunk during the period of calcification of the permanent teeth or from birth to about 9 years of age. Methods of removing fluorides from water are still in the experimental stage, although some are promising. The safest procedure where fluorides are present is for parents to have their children drink rain water, or a new supply free from fluorine should be developed. This trouble is not uncommon in west Texas and some other parts of the state.

Lead poisoning is caused by water which has been in contact with lead pipes. Soft, corrosive or acid waters are especially active in taking up lead and if the supply is of this character use of lead pipe should be discouraged. Lead is cumulative in the body and it may require months of consumption of lead-bearing water before symptoms appear. The standards of the U. S. Public Health Service place the upper limit of lead in water at 0.1 part per million.

Goiter is a disease of the thyroid gland frequently indicated by swelling of the neck. It is not caused by water but many investigators have found it to be unduly prevalent, especially among children, where the water supply is lacking in iodine. Apparently only a small amount of iodine is needed, but if it is not obtained in the food or water supply goiter may result. A few cities have placed sodium iodide in the water supply for two 2-week periods in the year, but a more popular method is use of iodized salt or furnishing of iodide tablets to school children.

There is no scientific evidence that hard waters, or any of the minerals found in water, have any part in the causing of gall stones or kidney stones. Some medical authorities not only deny the existence of this possibility but claim that hard waters are actually beneficial to the nerves, tooth formation and body weight. Laxative effects noted when there is a change of water are caused by a difference in the mineral content and the body soon adjusts itself to the change.

COLON BACILLI.—*Colon bacilli,* also called *b. coli* * and ''gas formers,'' are harmless but highly significant bacteria which are frequently found in water. Following are the important facts concerning them:

1. They normally live in the intestines of man and other warm-blooded animals and are excreted with bowel discharges. They do not increase in numbers while in water.
2. Their presence in water, therefore, indicates pollution with excreta or sewage and the possible presence of germs of typhoid fever, paratyphoid or dysentery.
3. *Colon bacilli* can easily be discovered in water by routine laboratory analyses, whereas there is no generally accepted test to prove presence or absence of disease bacteria.
4. Water treatment methods that will remove disease germs will also remove all or practically all *colon bacilli.*

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* *Escherichia coli* is the term now applied to *b. coli* by many bacteriologists and said to be preferable.

5. Therefore a water test showing no *b. coli* indicates a safe water, while their presence indicates a dangerous or at least suspicious water.

Unfortunately there are some organisms that react in the laboratory tests in the same manner as *colon bacilli* and cannot be differentiated except by very elaborate procedure. These organisms, of which *bacillus aerogenes* is one, are not of bowel origin and are common in surface soil. Their presence in a well water indicates entrance of undesirable surface or shallow ground water and in a treated water shows inefficient treatment methods. Accordingly their presence is also classed as suspicious.

OTHER BACTERIA IN WATER.—Many kinds of bacteria live in water, their numbers depending upon temperature, food supplies present, etc. Tests are made to determine the total numbers of bacteria, or rather the total of those whose presence can be shown by the tests. Such determinations are of value in checking water treatment methods since treatment should greatly reduce the total bacterial population.

ALGAE.—Algae are small water plants. They may be present in sufficient numbers to cause turbidity of the water, green scum at the surface or slimy growths on submerged surfaces. They require sunlight to develop and thrive especially in water containing some organic matter and carbon dioxide. In their life processes they use carbon dioxide and release free oxygen to the water. Certain species cause tastes and odors, after death and decomposition, but they do not cause disease. Control methods are discussed in Chapter VII.

OTHER LIVING ORGANISMS.—*Protozoa* are microscopic one-celled animals. Some of them are much like algae in their effects. A few cause disease. Amebic dysentery, for example, is caused by a protozoon called an ameba. *Fungi* sometimes occur in water in troublesome quantities. They do not require sunlight and may grow in large amounts in water mains. Control methods, other than elimination of sunlight, will be the same as for algae. *Worms* of various kinds are sometimes found in collecting basins, open wells, etc. They are in most cases the larvae of certain gnat flies which have laid their eggs on the water surface. The worms are likely to be found in large numbers at the basin bottom but water disturbances may cause them to be pumped into the mains. Basins should be covered to prevent access of the adult flies to the water surface.

TURBIDITY.—Although turbidity or murkiness of water may be caused by organic constituents, as algae, generally it is due to such mineral matter as clay, silt or fine sand. The amount and character of turbidity in a surface water will depend upon the type of soil over which it has run. Materials causing turbidity are not dangerous but they should be eliminated to add to the attractiveness and palatability of the water. Turbidity is measured in parts per million by weight of suspended matter, and in a potable water it should not exceed 10 and preferably 5 parts per million.

DISSOLVED MINERALS.—Water in passing over or through the earth dissolves many minerals. The greater the length of travel, particularly underground, the greater will be the mineral content. Deep-well waters usually, therefore, have more minerals in solution than shallow waters. If they have accumulated large amounts of sodium sulfate (Glauber salts), magnesium sulfate (Epsom salts), and considerable alkaline salts, they are sometimes called mineral waters and used for medicinal purposes. The total solids in public supplies should not, according to the U. S. Public Health Service, exceed 1000 parts per million. The total solids will, under normal conditions be almost entirely dissolved minerals. Many Texas well waters cannot satisfy this requirement. No harm apparently is done by the high solids except that newcomers to town may dislike the taste. The common dissolved minerals will be discussed briefly.

Calcium carbonate, chalk, calcite or limestone, is alkaline and hardness producing. It is only slightly soluble in water and therefore is not a problem in itself.

Calcium bicarbonate is formed where water containing carbon dioxide comes in contact with calcite or limestone in the ground. The carbon dioxide is only loosely bound to the calcium carbonate and may be dissociated from it with heat or chemicals. After the dissociation the remaining calcium carbonate reverts to its insoluble state and will precipitate and settle. If this happens in a steam boiler, or even in the humble teapot, an incrustation or scale will form. In addition to forming scale this mineral causes hardness and alkalinity.

Calcium sulfate or gypsum causes hardness. It is more soluble in cold than in hot water and accordingly it will leave solution in steam boilers to precipitate and cause a hard scale on the boiler tubes.

Calcium chloride causes hardness. In steam boilers the heat causes formation of acid which rapidly pits the tubes.

Magnesium carbonate, magnesite or dolomite, and *magnesium bicarbonate* have the same properties and action as calcium carbonate and bicarbonate.

Magnesium sulfate, Epsom salts, adds to hardness and will leave scale in steam boilers. In amounts greater than 500 parts per million it will have noticeable laxative effects.

Magnesium chloride has the same effects and properties as calcium chloride.

Sodium carbonate, washing soda, and *sodium bicarbonate,* baking soda, cause alkalinity and softness in water. They will unite with grease to form a soap, and waters containing them in considderable amounts feel slippery because a soap has been formed with the oil of the skin.* In steam boilers and hot water heaters they will release carbon dioxide, which is corrosive to the metal of the tubes.

Sodium chloride, common salt, will cause a perceptible taste if present in amounts greater than 200 parts per million. If there is more than 3000 parts per million the water will be practically undrinkable.

Sodium sulfate, Glauber salts, will have a laxative effect if there is more than 500 parts per million present. In large but uncertain amounts it may cause foaming or priming of steam boilers.†

IRON AND MANGANESE.—Iron is quite common in water because of the wide distribution of iron in the upper soil and underground formations. Water containing carbon dioxide will dissolve iron and form ferrous bicarbonate. While the water is underground the iron will remain in solution but when it can take oxygen from the air there is a rapid oxidation of the bicarbonate into an insoluble oxide, or the familiar iron rust. In the process fine red particles form which finally will settle as a rusty sediment. The sediment will form deposits in water mains, stain plumbing fixtures and discolor clothing. An unpleasant taste may also be noted. Presence of dissolved oxygen and carbon dioxide will make waters corrosive and these will rust the iron water mains, discharge some iron oxide at the faucets, and cause stains. The trouble is particularly likely to occur at dead ends in the mains, partly because rust is likely to collect there and partly because decomposition of other material lodging where water circulation is poor increases carbon dioxide and speeds up corrosion. Iron will stimulate undesirable bacterial growths, the crenothrix organisms, in the mains. These bacteria oxidize iron and cause red water, but are also responsible for bad tastes and odors. It will be seen that the troublesome red water may be caused by iron in the original water supply or by iron taken by corrosion from iron or steel water pipes. Trouble may be expected if there is more than 0.3 part per million of iron in the water. Treatment methods are available to remove iron from water and also to correct corrosiveness.

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* Laundries sometimes use acetic acid to overcome this condition and Epsom salts placed in bath water also prevent the slipperiness.

† There are other causes of foaming and priming in boilers.

Manganese is similar to iron in its action except that it causes dark brown or black stains. It will also accumulate in water mains and upon the sand grains of filters. It is less common than iron but is frequently associated with it. The combined amounts of iron and manganese should not exceed 0.3 part per million. Manganese can also be removed from water by treatment.

Color.—A true color is caused by material in solution and should not be confused with an apparent color caused by suspended matters. True color in natural waters is caused by vegetable dyes from decomposing leaves or other vegetable matter. Combinations may occur. A substance from rotting oak leaves and iron in the water will combine to cause an inky color or tint. Generally, however, the color will be brown or dark red, caused by tannic acid or humic acid. Swamp waters are likely to be highly colored and therefore slightly acid. The color of a potable water should not exceed 10 on the platinum-cobalt scale.

Organic Dissolved Impurities.—This term is applied to a number of water constituents which indicate past or present pollution of water. They include organic nitrogen, albuminoid ammonia, free ammonia, nitrites, nitrates, compounds which are all derived from organic matter. They do not cause disease, are present only in very small amounts and their effects are negligible. The chemist, however, can make tests for them and thereby form an opinion as to the safety of the water. For example, if the free ammonia, albuminoid ammonia and organic nitrogen are relatively low, while nitrites and nitrates, particularly the latter, have been formed it indicates that the pollution occurred far enough in the past to permit more or less complete oxidation of the polluting matter. Probably while this has taken place disease bacteria will have died off in the water and it may be safe. Such a set of tests is known as sanitary chemical analysis. The sanitary chemical analysis may also include the following determinations: chlorides, since a high chloride content may, under certain conditions, indicate sewage pollution; oxygen consumed or bio-chemical oxygen demand, since these indicate the amount of organic matter in the water.

Tests for *colon bacilli* are easier to make, however, and more definite in their indications. Consequently the sanitary chemical analysis is little used for water although it is of importance in testing sewage and studying stream pollution.

GASEOUS IMPURITIES.—*Hydrogen sulfide* is not uncommon in ground waters. Water which contains organic matter and comes in contact with sulfates as it passes through the ground may change the sulfates into hydrogen sulfide. The disagreeable rotten-egg odor is very characteristic of this gas and there will be many complaints if it is not removed. A potable water should have no odor of hydrogen sulfide. It is highly corrosive in its action but is not injurious to persons drinking water having the amounts generally encountered. Breathing air containing large amounts for long periods, however, is dangerous.

Dissolved oxygen means the free oxygen held in solution in the water and not that held in chemical combination to form H_2O. It enters water by solution from the air, or from the life processes of algae, the latter being especially likely to occur during warm weather in reservoirs, lakes and sluggishly flowing streams. Ground waters may contain little or no dissolved oxygen; rain waters will contain large amounts; surface waters will have much or little depending upon the amount of pollution in the water and action of algae. Organic matters undergoing decomposition use oxygen and therefore presence of little or no oxygen in surface waters indicates pollution. At best, however, water contains but little for at usual temperatures saturation occurs at about 9 parts per million. Oxygen is corrosive in water, particularly when there is carbon dioxide also present.

Carbon dioxide is found in ground waters that have come in contact with decomposing carbonaceous matter at or near the ground surface or with similar material deposited in past geologic ages. In surface waters it is found as a result of decomposition of organic matter. It greatly increases the solvent power of water and makes it very active in corroding the metals of pipes. It may be classed as free carbon dioxide or it may be combined with calcium carbonate or sodium carbonate to form the bicarbonate, in which case it is known as ''half-bound'' carbon dioxide and may be driven off by heat. ''Free'' carbon dioxide is not really free but has formed a compound with water known as carbonic acid. Carbon dioxide can be removed by methods that are described in Chapter X.

Methane is found in a few ground waters. It is a product of the decomposition of organic matter deposited in past ages. There may be a slight odor in the water caused by other materials accompanying the methane but otherwise this gas has no significance. Closely allied to methane are the impurities causing a ''stagnant'' odor or taste not uncommon in waters taken from the deeper portions of lakes and likely to be noted in lake or reservoir water supplies when a spring or fall overturn has brought the deep water to the surface. The odorous material is dissolved gases or solids generated by organic matter, dead algae, etc., decomposing in the deep water in the absence of dissolved oxygen.

ALKALINITY AND ACIDITY.—Examination of Fig. 1 will disclose the common causes of acidity in water. Of these carbon dioxide is the most important. Certain chemicals (coagulants) which are used in water treatment, as aluminum sulfate (alum) and ferrous sulfate (copperas), unite with and neutralize alkalinity and may cause the water to become slightly acid. If the alkaline minerals are not present in sufficient amounts to combine with the coagulants used, in other words, if the alkalinity is too low, it can be increased by adding lime or sodium carbonate (soda ash). Acidity also enters into the complicated process of corrosion, and correctional methods include increasing the alkalinity.

Caustic alkalinity does not occur naturally in waters but sometimes results from treatment processes. Water-softening plants frequently use lime and if large amounts are used the calcium hydroxide formed by the lime and water may be present in excess over that needed to reduce the carbonate hardness. Caustic alkalinity will then be present and will be indicated by pH values of 9.5 or more, depending on the phenolphthalein alkalinity. Caustic alkalinity has the advantage of killing *b. coli* and disease bacteria, and for this purpose is occasionally employed, but it imparts an unpleasant flat taste to the water.

There are two methods of expressing acidity and alkalinity. One is based upon the amount of calcium carbonate needed to neutralize the carbon dioxide or carbonic acid, or, in the case of alkalinity, the amount of alkaline minerals present in terms of equivalent calcium carbonate. When so found both acidity and alkalinity are expressed in parts per million. Using this method of determination a water may show alkalinity caused by bicarbonates, and at the same time acidity, caused by free carbon dioxide.

Another method of expressing the acidity or alkalinity of a water is by its pH value. This depends upon electrochemical conditions in the water which are accompanied by the formation of electrically charged ions, some of which are positive, the hydrogen ions, and the others negative, the hydroxyl ions. The greater the concentration of hydrogen ions the greater the acidity of the water. The scale of pH values varies from 1 to 14. A pH of 7 indicates neutrality, below 7 indicates an acid water and above 7 an alkaline water. Natural waters range between about 6.0 to 8.3 with most of them somewhat above 7. A few Texas ground waters, however, will be found at 9 or even more.

HARDNESS.—A water is hard if it requires much soap to produce a lather, although it has other highly important undesirable effects—interference with some industrial processes, and scale deposition in boilers, which causes much wastage of fuel. The four important compounds causing hardness are calcium bicarbonate, magnesium bicarbonate, calcium sulfate and magnesium sulfate. The first two were formerly designated as temporary hardness because heat softened the water by driving off the half-bound carbon dioxide, causing the practically insoluble carbonate to precipitate and settle out. It is now considered more desirable to designate the bicarbonates of calcium and magnesium as *carbonate hardness* and the other or permanent hardness, the sulfates and chlorides, as *non-carbonate hardness.* Calcium and magnesium carbonates are themselves soluble to the extent of about 35 parts per million, but this is a negligible amount. Hardness caused by iron is likewise of no importance although iron is very troublesome in other ways. Hard waters can be softened by methods given in Chapter X. If a water supply has a total hardness of more than about 125 parts per million the cost of softening the water will be more than offset by the savings in soap.

INDUSTRIAL WASTES.—Some industries discharge liquid wastes into streams and lakes, where they may cause odors, kill fish and endanger water supplies. Generally, however, self-purification, combined with treatment at the water plant, will overcome the trouble. Phenolic and creosote wastes have caused trouble for a few Texas cities. These substances, even if present in very small amounts, will cause trouble in a treated water by combining with chlorine to form an unpleasant medicinal taste. Another waste troublesome in Texas is salt water from oil fields. Establishment of an oil field upon a city's water-catchment area should always be followed by immediate investigation of possible salt water troubles.

SEWAGE POLLUTION OF WATER.—When sewage is discharged into a stream or lake important effects can be noted in the water. The magnitude of the effects will depend upon the strength of the sewage; the treatment that it has received, if any; the amount and character of the water in the stream or lake; the presence of currents, rapids, falls, pools, etc. The effects will be discussed in detail.

1. The decomposing solids of the sewage quickly use up the dissolved oxygen in the water. If the amount of sewage is large, say more than one-twentieth of the water, there may be highly disagreeable conditions; the water will be turbid, black and evil smelling; fish will be killed; banks of black mud will form.

2. The number of bacteria will be increased. *Colon bacilli* will be numerous and will be accompanied by disease bacteria.

3. Chemical tests will show a low pH value, presence of carbon dioxide, much free ammonia, albuminoid ammonia, organic nitrogen, and hydrogen sulfide but no dissolved oxygen. The oxygen demand will be high.

As the water runs downstream, or is held more or less quietly in a lake, natural processes will improve it. Sedimentation will clarify the water and the settling solids will remain on the bottom to undergo decomposition into inoffensive materials. Oxygen will be absorbed from the air at the surface and will be available to oxidize organic matter, some of it into nitrates, which are plant food. This is a biochemical action and certain bacteria enter into the process. When sunlight can enter the clarified water algae will appear and perhaps grow very luxuriantly, using as food the nitrates formed by the oxidizing bacteria and the carbon dioxide from the earlier decomposition. The oxygen they release will aid the oxidizing process and further improve the water. Unfavorable conditions as to food, temperature and surroundings will greatly reduce the number of sewage bacteria. A second examination of the water will show the following conditions:

1. There will be no odor except perhaps that of algae. The black color will have disappeared and the remaining turbidity will be that caused by silt or algae. Fish will have reappeared and in general water life will be more abundant.

2. The number of bacteria per cubic centimeter will be fewer. *Colon bacilli* will also be much reduced in numbers, although they will still be present. It is also highly probable that a few disease bacteria will have survived.

3. A chemical test will show dissolved oxygen in the water, perhaps up to the saturation point for the water temperature. With many algae present it may even be higher during the daylight hours. There will be little ammonia, either free or albuminoid, some nitrites and considerable nitrates. The pH value will probably show alkalinity, and the oxygen demand will be low.

The changes will have been brought about by the process known as self-purification. Surface-water supplies, by the time they have reached a city intake, have generally undergone considerable self-purification and this makes treatment somewhat easier. A few important matters must be understood. Self-purification cannot be depended upon to make an unsafe water safe. Only controlled scientific treatment will accomplish this. Nearly all surface waters receive some dangerous polluting materials occasionally or continuously. Therefore they must have appropriate treatment methods applied to them before they are made available to the public.

CHAPTER II

SURFACE SUPPLIES

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ORIGIN OF WATER.—There is some difference of opinion among geologists concerning when and by what processes the earth's water originated. A logical explanation is that as our planet cooled from its original molten state to below 212 degrees F. watery vapors in the atmosphere condensed into liquid and settled in low spots of the shell, augmented perhaps by occluded water squeezed or otherwise forced out of the underlying rock mass. These low areas became oceans, seas and minor water bodies, that now, though changed in size and shape, constitute our natural reservoirs.

The sun's rays vaporize water from the oceans and other bodies of water; the atmosphere absorbs the watery vapors; winds carry these over the land; expansion of the moisture-laden air as it rises, as well as contact with chilly mountain breezes, condenses the vapors to rain drops that fall upon the earth. Some of the rain runs off in the rivers to lakes and oceans; a part straightway evaporates from the ground surface; a part enters into the earth, there to nourish vegetable life, and ascending through its tissues, to transpire into the air; and a part percolates more deeply to form the ground water, some portion of which will later appear in wells or will outcrop to form springs and the dry-weather flow of streams.

The importance of water evaporated from land surfaces and transpired by vegetation is indicated by the following statement of Mead.*

"The precipitation on continental interior lands is, however, the phenomenon in which the engineers are more generally interested, and the source of this precipitation is derived most largely from the moisture that obtains from the continental evaporation, from land surfaces and from the surfaces of rivers, lakes and swamps and indirectly from the transpiration from animal and vegetable life. By far the greatest portion of the rainfall on continental areas is thus returned to the atmosphere, for the discharge of the rivers of a continent into the seas will not equal half of the continental rainfall.''

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* Mead, D. W., "Hydrology," p. 164. Published by John Wiley & Sons, New York.

SURFACE WATERS.—Municipal surface water supplies make use of the following: (*a*) normal flow in streams; (*b*) natural lakes; (*c*) stored normal flow and storm waters (impounding reservoirs).

Normal flow.—In many states streams have a quite dependable flow throughout the year; in such cases, if the minimum discharge of the stream be of sufficient volume, storage by dams and reservoirs to assure adequate supply at all times is unnecessary. Texas streams, however, with but few exceptions, have unusually variable flows. During periods of low rainfall, some may have no flow whatever and if they are to be utilized as sources of municipal supply, their storm waters and rainy-season flows must be impounded and stored for use.

Natural lakes.—Some fortunate cities which are located near large lakes are able to supply their needs without concern as to fluctuations in amount of available water. Cities located along the Great Lakes are examples. A few other cities tap mountain or other lakes and bring water long distances through pipe lines or conduits. In Texas, however, very few natural lakes have been developed and used for municipal supplies.

Stored normal and flood flows.—The large majority of Texas cities using surface supplies must depend upon streams having flows varying from high flood discharges to little or no flow, a condition requiring the construction of an impounding reservoir, which stores a part of the high flows for use during low-flow periods. In connection with the development of a supply from such a source the following information must be known: (1) the expected water demand, not merely at the present time, but over a predetermined future period, say 30 years or even longer; (2) the water rights of property owners downstream, since it may be necessary to allow water to pass the dam to satisfy those rights; (3) the yield of the stream, including fluctuations in stream flow from year to year and from month to month within the year.

Of the three types of data mentioned that dealing with stream flow presents most difficulty. The difficulty arises because, for the smaller Texas streams, there are no streamflow records, although they are available for the larger streams for longer or shorter periods. Absence of streamflow data makes it necessary to estimate what the yield of a stream will be by estimating the proportion of the rainfall that will run off. Accordingly the most important study made in connection with a surface-water supply may be the gathering and interpretation of data dealing with rainfall and the physical conditions on the watershed which affect the proportion of the rainfall which will appear as runoff. The specific rainfall figures required are the average, maximum, and minimum annual rainfalls, the probable occurrence of a series of dry years, and the distribution of the rainfall through the months of the year. The study of water in all its states and its distribution over and under the earth is known as hydrology and a number of textbooks dealing with it will be found in the bibliography at the end of this chapter. A very brief discussion is given here, with particular applications to Texas conditions.

RAINFALL

THE ANNUAL AVERAGE.—Rainfall is expressed as depth in inches. The average in Texas for the whole state is about 30 inches per year, varying from 45 inches along the coast at Galveston and decreasing in amount toward the west, so that the average at El Paso is 10 inches and at Amarillo 20 inches. Some idea of the variations in the annual average to be expected can be obtained from the records of Fort Worth for the period of years 1900–1936, inclusive. The average of this 37-year period is 32.74 inches, with a maximum of 51.03 inches, or 56 per cent above the average, and a minimum of 17.91 inches, or 45 per cent below the average. These figures may be considered as being fairly representative of Texas records. In round numbers, then, something like 50 per cent above and below the average rainfall may be expected for a single year.

The possibility of a succession of dry years may also be illustrated by the Fort Worth rainfall records. Beginning in 1909 and extending through 6 months of 1913, a period of rainfall below the average occurred as follows, deficiency being the difference between the actual rainfall and the average:

Year	Rainfall	Deficiency
1909	20.93 in.	11.81 in.
1910	17.91 "	14.83 "
1911	27.03 "	5.71 "
1912	26.35 "	6.39 "
1913 (6 mo.)	12.45 "	5.43 "
Total 4½ yr.	104.67 in.	44.17 in.

It will be seen that the accumulated deficiency nearly equaled 1½ years of average rainfall. Such a series of dry years might prevent a newly constructed reservoir from filling for several years and might have serious consequences if an existing reservoir is being taxed to capacity. It is apparent also that reservoir capacity must be arrived at after considering the possible occurrence of such a dry period.

DISTRIBUTION OF RAINFALL THROUGHOUT THE YEAR.—The distribution of rainfall throughout the year is of great importance in the production of streamflow. Table I shows the actual monthly rainfalls at Fort Worth and the monthly averages. Since more water is lost to vegetation during the growing period and there is more loss by evaporation in warm weather, it is apparent that rain fall-

TABLE I.—DISTRIBUTION OF RAINFALL BY MONTHS. FORT WORTH, TEXAS

Month	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	Average 1900–1930
Jan.	1.45	.46	2.08	.84	1.79	9.07	1.96	1.86	3.70	.67	1.83
Feb.	1.77	3.53	2.78	1.08	2.84	4.92	2.47	1.67	3.29	.45	1.86
Mar.	2.19	1.10	1.39	2.86	4.20	.63	2.18	4.26	1.40	.63	2.41
Apr.	3.66	5.70	2.06	2.37	1.97	3.43	1.57	2.39	3.06	.99	3.96
May	.44	3.77	5.38	10.37	2.42	6.03	4.67	.82	9.15	9.43	4.53
June	3.33	11.58	.20	1.87	2.43	3.04	.03	—	7.22	.03	3.29
July	1.53	4.24	.43	.37	.44	2.07	5.70	.08	.89	2.35	2.61
Aug.	.80	2.13	Trace	3.12	3.38	2.92	2.75	.13	.70	.23	2.47
Sept.	4.00	.45	2.29	1.19	1.25	10.80	4.94	4.90	3.61	7.30	2.31
Oct.	4.47	4.15	2.12	7.96	3.39	1.66	1.24	.12	4.01	3.72	2.97
Nov.	.58	1.97	1.50	1.71	2.78	1.56	.66	2.30	1.65	.46	2.42
Dec.	.59	5.50	.41	2.08	2.73	4.90	2.13	.56	2.26	1.84	2.01
Total	26.82	44.58	21.09	35.82	29.62	51.03	30.30	19.09	40.94	28.15	32.55

ing during those months of the year is of less value to the water works man than that falling in other months.

Mr. George W. Rafter, a distinguished hydraulic engineer, said concerning rainfall distribution and stream flow, ''The writer has found it very convenient to divide rainfall and runoff (stream flow) records into the three periods, those of storage, growing, and replenishing, with a water year beginning December 1 and ending November 30th. The storage period includes the months from December to May inclusive, during which the evaporation and absorption by plants are relatively slight, and a very large proportion of the rainfall appears in the streams.

''The growing period, June to August inclusive, includes the period of active vegetation, where evaporation and absorption by plants are most notable. During this period not more than 0.1 of the rainfall appears in the streams and sometimes not more than 0.05, or even less. Ground water tends to become lower and lower during this period unless the rainfall is much higher than the average. In the replenishing period, September to November inclusive, with the normal rainfall, ground water tends to recover and the runoff is larger than in the preceding period. This period is replenishing in that there is a tendency to return to normal conditions.

''No hard and fast rule, however, can be laid down as to the beginning and ending of these periods. In some years the beginning of the water year should be placed at November 1, instead of December 1, while in others the storage period may end with April. Very often one period runs into another, but after considerable study the foregoing divisions have been accepted, as, on the whole, best representing all conditions.''

The periods of storage, growing, and replenishing, as outlined by Rafter, apply only approximately to Texas conditions, as they were based upon observations made in the northern states. Furthermore, conditions in Texas vary so widely that differences will be noted within the state. Not only is there a difference in the mean annual temperature and rainfall, but the mean monthly precipitation figures differ, with far greater spreads between the maxima and minima, while the main crop growing periods are also different. The effect of these conditions is to make normal streamflow in Texas less and far more inconstant than in the North.

RAINFALL AND RUNOFF

Rainfall records covering a watershed are usually fairly complete. In the absence of actual streamflow measurements the difficult problem arises of estimating what proportion of the rainfall will appear as runoff in the stream under consideration. The proportion of runoff in the stream will depend upon the rainfall distribution, which has already been discussed, and also upon the physical character of the catchment area or watershed. The problem is further complicated by the fact that much of the water which percolates into the ground may later appear as dry-weather flow in streams, that has been derived from springs.

EFFECT OF PHYSICAL CHARACTERISTICS.—The slope of the river bed (commonly measured in feet per mile), and more particularly the side slopes of the valley toward the stream, affect the percentage of rainfall that reaches the stream. Steep slopes cause a greater proportion of runoff. Obviously valley side slopes of 100 feet per mile will more quickly and effectively carry rainfall to the stream than will side slopes of 10 feet per mile. Again, although later contributing its share to stream flow, a deep sandy soil will give less surface runoff than a clayey formation. Lake Bridgeport, Texas, with a drainage area of 1096 square miles, largely with rock and shale surface, has but a few sandy areas, yet these latter, for weeks at a time, furnish flow from springs sufficient to supply evaporation loss on a 9000-acre lake surface.

Trees, brush, grass, weeds, and crops on the side slopes also affect stream flow in various ways. They allow evaporation from water caught on the leaves. By holding water so that it drips slowly to the ground, and by presenting obstructions to surface flow, vegetation encourages percolation into the ground, from which much of the water is taken by the plants and transpired into the air through the leaves.

The general shape of the drainage area, i.e., whether long and narrow, or fan-shaped, is a factor in runoff, the latter shape being conducive to more rapid concentration of the flow of tributaries, hence earlier and perhaps higher rises or flood flows.

ESTIMATION OF RUNOFF.—The actual per cent of rainfall appearing as runoff will depend upon the factors already discussed. It will be of interest, however, to make a calculation of the amount of runoff that might be expected from an assumed watershed. Let it be assumed that the hypothetical stream is called Mesquite Creek, that it is in central Texas and the average annual rainfall is 30 inches on its 500 square miles of drainage area (Fig. 2). The area is approximately elliptical in shape and 36 miles in length, measured from upstream to downstream end. Its width near the middle is about 20 miles. Its general slope is 8 feet per mile along the long way of the valley and 5 feet per mile in the river bed. On each side of the river bed the valley sides slope upward 10 feet per mile for a distance of 1 mile. According to T. U. Taylor[1] the runoff of the Trinity River at Dallas over a period of 10 years was an average of 6.76 per cent of the rainfall, with a variation of 2.60 per cent to 16.48 per cent. Other records indicate that the average runoff from the whole state is approximately 41,000,000 acre feet, or 0.25 acre foot of water for each acre of area of the state. This, of course, is equal to a depth of 3 inches of water on each acre and this is equivalent to 160 acre feet per square mile.

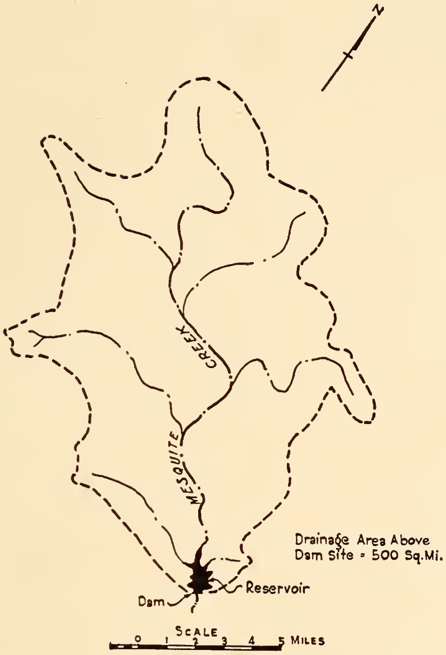

FIG. 2. Watershed of Hypothetical Mesquite Creek.

It will be assumed that the runoff on the Mesquite Creek area will be 7 per cent, although, as previously indicated, this figure should be arrived at after consideration of the characteristics of the watershed. From the 500 square miles of drainage area, and with a rainfall of 30 inches, the annual runoff would be 56,000 acre feet or 112 acre feet per square mile. For an impounding reservoir to be feasible there should be a bottle neck at the lower end of the watershed that would permit a dam and spillway, probably totaling about 4000 feet in length, to be constructed. A solid rock foundation for the dam, or at least for the spillway, is most economical, although concrete or wood piling has sometimes been used in its place.

A dam of this size would probably form a lake some 3 miles long, 2 miles wide, and 30 feet deep at the middle point, impounding about 25,000 acre feet of water. Such a reservoir would probably supply the needs of a city of 100,000 population, including actual consumption, loss through evaporation from the water surface, and loss by seepage into the reservoir bed and through the earth dam. It would also care for the normal siltation, which would possibly amount to 0.5 acre foot per square mile of watershed area or, in this case, 250 acre feet per year. Discussion of evaporation from the reservoir surface and siltation will be found later in this chapter.

FLOOD FLOW.—The great stream flows resulting from storms are of much importance in surface-water supply projects. If the spillway, as constructed, is too small the dam will be overtopped by the water and serious damage will result. An earth dam will probably be completely destroyed and loss of life, in addition to much property damage, may result. If reliable streamflow records, covering say 50 years, are available, a margin of safety can be added to the greatest recorded storm flow, and the length and depth of the spillway computed. If, however, there are no reliable long-time records, recourse must be had to records of other streams having as similar geological and weather conditions as may be.

Table II gives the maximum flood discharges recorded for watersheds of various areas. It will be noted that the smaller the area the greater is the flood flow to be expected. The figures given in the table are merely illustrative and do not apply particularly to Texas conditions. Each Texas project should receive individual study based upon the best, longest, and most applicable hydrological records.

Applying more assumptions to our hypothetical Mesquite Creek, the flood flow would be arrived at as follows: If the longest flow record applicable to the stream were 25 years and showed a peak of 50,000 cubic feet per second or 100 cubic feet per second per square mile, it would be wise to assume a peak flood of say 150 cubic feet per second per square mile or a peak discharge of 75,000 cubic feet per second. It will be of interest to note that the Clear Fork of the Trinity River, at Fort Worth, has a drainage area of slightly over 500 square miles. Its greatest flow in 60 years occurred in April, 1922, and reached 71,000 cubic feet per second or about 142 cubic feet per second per square mile.

TABLE II.—RELATION BETWEEN WATERSHED AREA AND MAXIMUM DISCHARGE

Area Square Miles	Maximum Discharge Cubic Feet per Second per Square Mile
1	4,000
10	2,500
100	1,000
500	175
1,000	125
2,000	75
5,000	35
10,000	20
1,000,000 (Lower Mississippi)	2.5

DAMS AND RESERVOIRS

The design of dams and spillways is a procedure which necessitates both technical ability and engineering judgment, but discussion of the matter, even though space were available, is scarcely appropriate in a manual for operators of water plants. Some knowledge of methods of construction may, however, be of value in meeting the maintenance problems encountered and accordingly a short description of the types of dams, the conditions and forces which they must withstand, is presented in the following pages.

FORCES WHICH ACT UPON DAMS.—A dam must withstand the water pressure. This depends entirely upon the vertical depth of the water along the upstream face of the dam. The length of the lake above the dam has no effect whatever upon the pressure. The dam must be so designed that the pressure will neither overturn it nor cause it to slide upon its foundation. Water pressure may also be transmitted from the reservoir through a pervious formation to the base of a masonry dam. Such pressure has an uplifting effect which may encourage overturning or sliding.

Although it has no effect upon water pressure, a great length of lake above the dam affects wave action. A long lake produces high waves which must be counteracted by increased height of the dam above high-water line, and, in the case of earth dams, protection of the face of the dam, by rip-rap paving or other material. In northern climates ice pressure against masonry dams is also considered.

MASONRY DAMS.—Dams of rock-fill, solid gravity section, hollow gravity section (Ambursen type), single arch, and multiple arches are used, principally in rock gorges having rock bottoms. Earth dams are by far the most common, although many of them have masonry spillways which have some of the characteristics of the masonry dam.

The foundation of a masonry dam is very important. It should preferably be of rock, capable of supporting the weight of the dam and free from seams and cavities that will permit an uplift from water pressure developed through seepage. Seamy rock must be filled with cement grout to prevent development of excess uplift pressure. A close bond between the masonry and rock is also a necessity to discourage sliding. Design is all-important in the case of the masonry dam and the problems of maintenance and operation are practically non-existent.

EARTH DAMS.—The earth dam is an embankment, usually constructed by one of two methods. The compacted-fill method consists of laying the earthy materials in horizontal layers, say 8, 10, or 12 inches thick. Each layer is then wetted and thoroughly compacted by rolling with heavy, grooved (or sheep's-foot) iron rollers. The hydraulic method consists of agitating the earthy materials with water by mechanical means and pumping them into the embankment, care being taken to deposit the very fine materials in the middle section of the structure, to form an impervious core. The coarser materials settle toward the outer slopes, an arrangement which, in the finished dam, allows the escape of the seepage

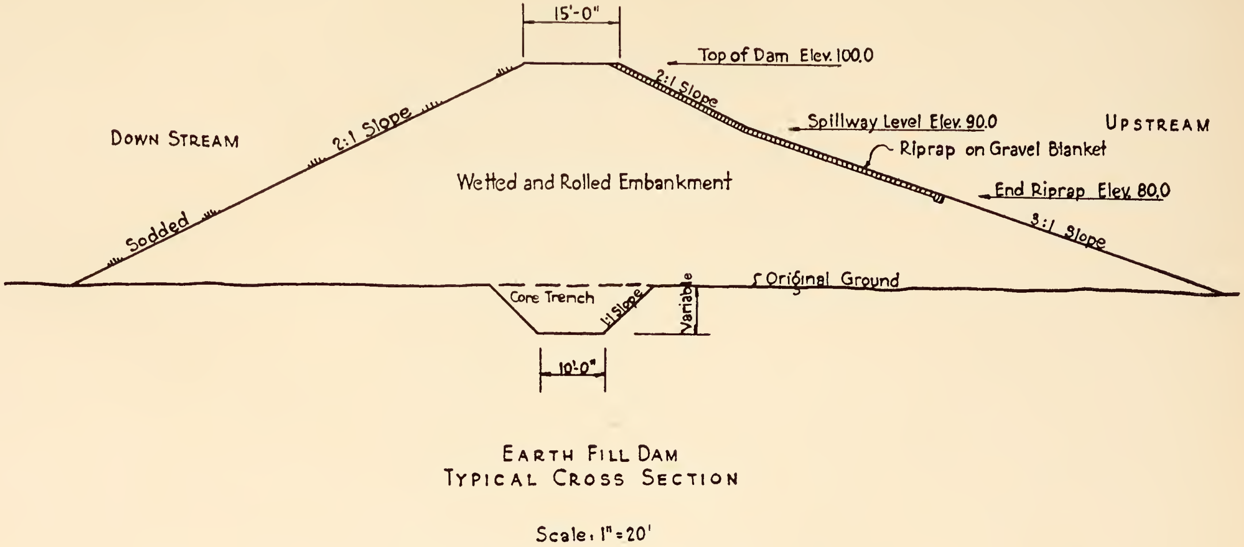
15'-0"
Top of Dam Elev. 100.0
2:1 Slope
Spillway Level Elev. 90.0
UPSTREAM
Riprap on Gravel Blanket
End Riprap Elev. 80.0
3:1 Slope
DOWN STREAM
2:1 Slope
Sodded
Wetted and Rolled Embankment
Original Ground
Core Trench
1:1 Slope
Variable
10'-0"
EARTH FILL DAM
TYPICAL CROSS SECTION
Scale: 1" = 20'

FIG. 3. Cross-section of a Filled and Rolled Earth Dam.

water which will probably enter the dam. The impervious core, however, will prevent excessive seepage.

Both methods, if properly applied, result in embankments substantially watertight. In both cases, the embankment is bonded to the earth of the site by a puddled trench of suitable dimensions on the longitudinal axis of the dam. Sometimes, in the case of wetted and rolled structures, this puddled trench is continued upward to form a corewall. Interlocking steel sheet piling extending below the bottom of the puddled trench is often driven to considerable depth to cut off or prevent percolation through any sand or gravel strata under the structure. Concrete core walls are occasionally built, but this practice is waning in popularity.

After the embankment is completed, the slopes, on both the lake and downstream sides, are trimmed to practically exact lines, removing any excess uncompacted material. The outer or downstream slope is usually planted in Bermuda grass for protection against erosion by rains. The lake slope is generally protected with some sort of pavement, heavy stone riprap, or concrete laid on a cushion of gravel or crushed rock, as wave protection.

SPILLWAYS.—The purpose of the spillway is to carry off safely the flood waters of the drainage area after the reservoir is filled. In order to design the structure properly, one must know, or estimate from the best data obtainable, the volume of the greatest flood the drainage area will produce, and the probable duration thereof. A brief discussion of flood flows has already been given and it is only necessary to emphasize here that it is exceedingly important that the spillway capacity be sufficient or the dam may be overtopped, which, in the case of earth dams, would probably cause failure. Some masonry dams, however, are designed to be overtopped, that is, the whole crest of the dam is the spillway. Occasionally the spillway may be constructed in a rock formation beside the dam in the stream bank or side of a gorge.

The common type of spillway is essentially a weir and it must be long and deep enough to care for the expected flow. The usual weir formulas are available for design, although, since the weir is not sharp crested, care must be taken that the proper coefficient is used. Generally the downstream side of the weir is curved to conduct the water from the horizontal to perhaps 45 degrees from the vertical, and to horizonal again with a minimum of dangerous shock to the structure.

At each end of the masonry spillway of an earthen dam there must be an abutment, essentially a retaining wall to support the end of the earthen embankment. Sometimes, where materials for concrete are cheap, the abutments are designed as a gravity section, by computations somewhat similar to those used in designing the section of the spillway. The abutments of the Lake Worth dam are of the gravity type. In other cases, abutments are made of reinforced concrete, as in the dam at Paris, Texas. The concrete base of the abutment extends underneath the earthwork and is weighted down by it; at suitable intervals there are counterforts of reinforced concrete tied into both the face wall of the abutment and the concrete base, thereby bracing the face wall against overturn. This type is known as a "counterfort" abutment.

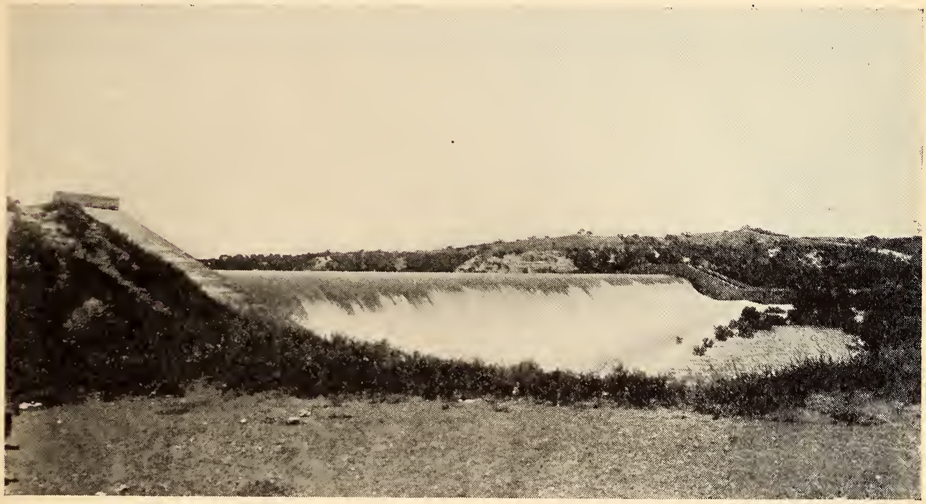

FIG. 4. Spillway of Lake Worth, Fort Worth, Texas.

The velocity of the water coming over a spillway in flood time is very high if the dam is high. As already indicated, spillways are usually curved to reduce shocks caused by changes of direction. Additional protection, however, is needed at the downstream end of the spillway to avoid damage by breaking the concrete or perhaps undermining it. This protection is obtained by continuing the concrete as a long slab or apron extending some distance downstream.

Unless the spillway is located on very hard rock it will be necessary to extend the apron a considerable distance downstream to lessen the eroding effect of this current on the valley floor. At the end of the apron a deep curtain wall is usually built, to protect against back-lash and eddies undermining the apron. Of late toothed sills 2 or 3 feet high have been built onto the aprons to reduce the velocity of the overfall, sometimes with a continuous sill at the end, thus forming a stilling pool or cushion between it and the dentations.

FLASHBOARDS AND FLOOD GATES.—As floods of sufficient volume to fill the entire safe capacity of the spillway are rare, the ordinary storage capacity of the reservoir may be augmented by the use of flashboards or flood gates placed along the spillway crest. Flashboards are usually not more than 2 or 3 feet in height and are of the removable or collapsing type. If a lake has a normal surface of 1000 acres, it is obvious that a set of flashboards 2 feet high would add more than 2000 acre feet, nearly 700 million gallons, to the storage capacity. The sloping shores, of course, would enable each foot in height to store more than the foot below it.

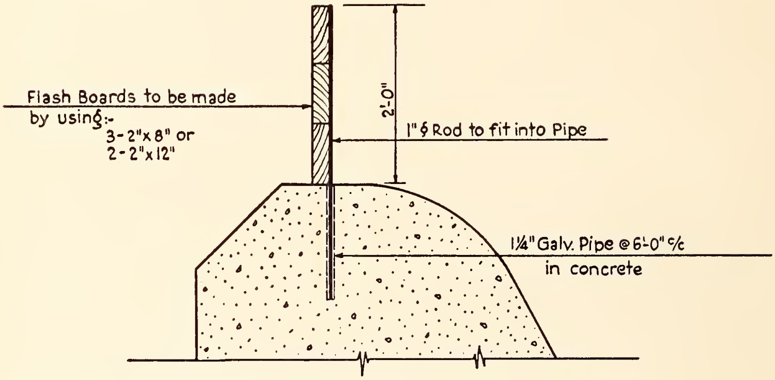
Flash Boards to be made by using:-
3-2"x8" or
2-2"x12"
2'-0"
1" ϕ Rod to fit into Pipe
1¼" Galv. Pipe @ 6'-0" c/c
in concrete

FIG. 5. Section through Flashboards.

The removable type has vertical sockets, generally of steel pipe, built into the top of the concrete spillway at suitable spacing. Steel uprights are set into the sockets and planks are placed against their upstream edges. Pressure of the water holds the planks in place, or they may be bolted to the uprights. Removal of the flashboards and their supports is easily accomplished by hand. "Brittle-steel" bars are sometimes used as supports. These break in flood time and the flashboards float downstream, possibly to be recovered later. A design for flashboards that will insure quick and certain removal or collapse in time of sudden, unexpected flood is very important.

The more permanent, collapsing type of flashboard, usually built of steel bars and plates, hinged at the top of spillway concrete, is rather complex in detail and requires only mention here. It is designed to collapse automatically when the water level has reached a predetermined height.

Flood gates are usually higher than flashboards and are raised either by hand or electric power. They are of various designs and are usually operated as integral parts of the dam. In time of flood they are raised to give room for the maximum flow to pass; on the wane of the flood they are lowered to catch the clearer water for storage. They are rather high in first cost.

LOSS FROM RESERVOIR BY EVAPORATION.—The hot dry weather of Texas causes heavy evaporation from the surface of a reservoir. Since evaporation depends upon both air temperature and humidity, it will be greatest in dry and least in wet years. Annual evaporation from water surfaces at Fort Worth varies from about 50 inches per year when the rainfall is 30 inches to about 70 inches when the rainfall is 20 inches. These figures indicate a net loss (the difference between the rainfall on the lake area and the evaporation) of from 20 inches to 50 inches, with a mean of 35 inches. This may be a serious loss of water that must be considered when necessary reservoir capacity is being computed. It is even more serious when it is considered that most of the evaporation occurs in summer months when replenishment, for the reasons already given, is at its lowest. Therefore, gross evaporation is probably the safer figure to consider in making investigations.

SILTING OF RESERVOIRS.—While loss of storage by evaporation, and in some cases by seepage, must, of course, be allowed for in computing net storage in a reservoir, another factor, siltation, is occasionally slighted or even overlooked. It is obvious, however, that rains falling on the soil of the drainage area will carry some amount of clayey, sandy, and gravelly materials into the reservoir, the amount varying with the intensity of the rainfall, the axial and side slopes of the valley, the amount and character of the natural vegetation and crops, and the character of the surface soil.

The important effect of siltation is shown in the following case. Lake Worth's original capacity in 1914, was about 36,000 acre feet; in 1925 it had been reduced by silt to 26,000, a loss of about 30 per cent or 2.5 per cent per annum. In 1936 the capacity was about 20,000 acre feet, of which about 14,000 acre feet are available for use, i.e., above the top of the supply conduit.

Various Federal and state agencies for several years have been active in alleviating soil erosion conditions in Texas and elsewhere throughout the United States, and erosion, consequently, is reducing. If continued this work should reduce the siltation of lakes and reservoirs.

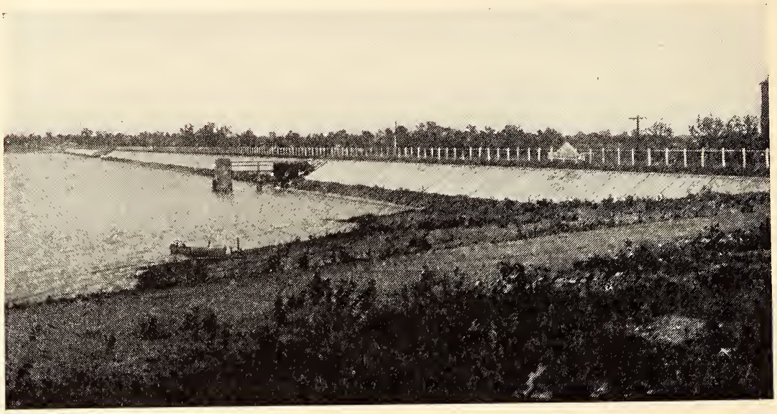

Fig. 6. Dam and Intake, Paris, Texas.

Cleaning the Reservoir Bottom.—Before a reservoir is filled with water it is advisable to clear the site of brush and trees. Wood constantly submerged does not rot although it will for years give more or less color and taste to the lake water. If the trees and brush are only partially submerged they soon die and present a very unsightly appearance. Finally they will rot off at the water line. Again, practically all Texas reservoirs are stocked with game fish, and trees or brush, if left on the bottom, will cause trouble and mental anguish to the disciples of Izaak Walton. It has become common practice, therefore, in Texas and elsewhere, to cut trees and brush close to the ground and burn or otherwise dispose of the timber and slash.

SUPPLY CONDUITS.—The lakes and reservoirs described are usually at some distance from the filtration and pumping plants which will treat and deliver the water to the consumer. The lake may be located at an elevation sufficient to permit the water to flow to the service plants by gravity. Should the lake, however, be lower than the treatment plant or pumping plant, low-service pumps must be installed at the lake.

In modern engineering practice, supply conduits are of cast iron, reinforced concrete pipe, and sometimes of riveted steel, welded steel, or steel-banded wood staves. The type to be used will depend upon the corrosiveness of the water that must be conveyed, local transportation conditions, first cost and expected maintenance costs. In any case the conduit should be designed to carry the maximum daily amount of water that will be needed, say 30 years after it is built.

To arrive at the maximum demand, population curves are drawn, based on U. S. Census figures or the best data obtainable, if Census figures are not available. In the case of comparatively old cities, population curves may be drawn that may be extended to indicate with considerable accuracy the population 30 years hence. With new small cities, however, whose Census figures cover but two or three decades, accurate or even approximately accurate prediction is well nigh impossible, and intelligent estimates, based upon knowledge or study of local conditions must be used. Further discussion of methods of estimating future population will be found in Chapter VIII.

WATER SUPPLY INTAKES.—A water intake, in the usual sense, is a structure in a natural or artificial water-body, provided with controlled opening through which a calculated amount of water may be admitted to a pipe or conduit of metal or masonry leading to a purification plant or pumping station.

Openings must be designed large enough to permit discharge of the computed maximum future demand, say thirty or more years in advance. They are located at several elevations, from near the bottom to a few feet below the average water level of the lake or stream. This arrangement of openings allows water to be drawn from the level which, at any time, will supply water having the least turbidity, lowest population of algae, or least amount of odors and tastes.

Gate-valves or sluice-gates are built in, or over, the openings. with stems or shafts extending upward to the operating floor of the gate-house. Operation of small and medium-sized valves is usually manual, while the larger sizes are operated by power winches.

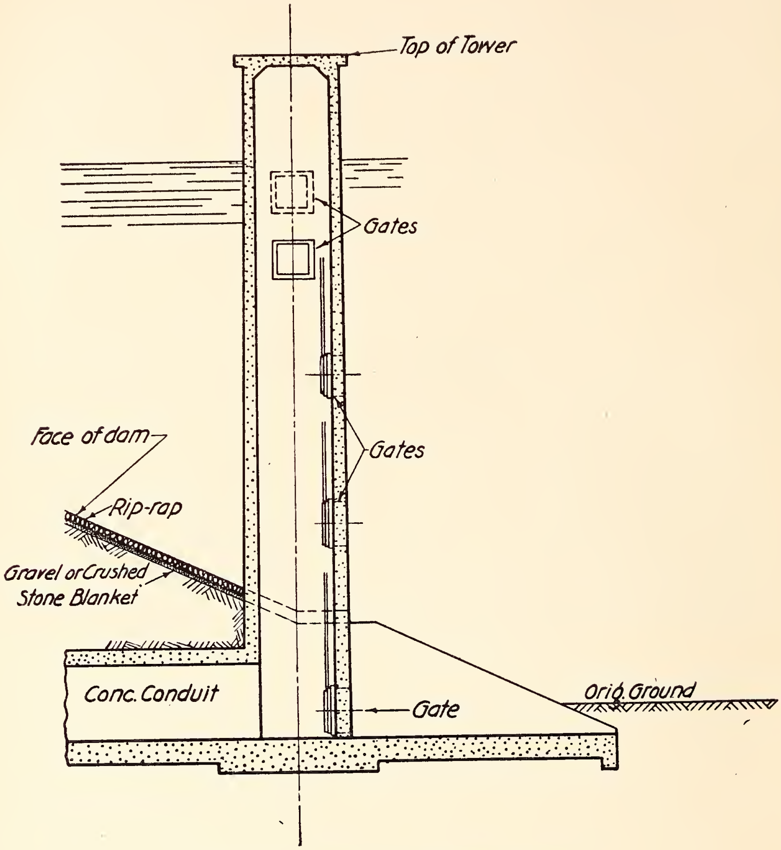
Top of Tower
Gates
Gates
Face of dam
Rip-rap
Gravel or Crushed Stone Blanket
Conc. Conduit
Gate
Orig. Ground

FIG. 7. Section of a Water Intake.

Figure 7 shows an intake-tower designed for the Phantom Hill Reservoir Dam now under construction to furnish an additional water supply for Abilene, Texas. This structure is typical in design and construction of intakes in reservoirs, although in this case the intake was designed merely to carry the creek flow during construction, and later to regulate lake levels and supply water to downstream users. Another intake nearer the city will be constructed later to furnish water for the pumping-filtration plant.

Other types of lake or reservoir intakes may be mentioned briefly. Cribs of concrete or timber may be constructed to discharge into tunnels or conduits. Chicago, for example, uses elaborate cribs or towers miles from the lake shore which discharge into tunnels driven through strata beneath the lake. Fort Worth derives its supply from a reinforced concrete crib out in Lake Worth with a gate house at the dam. The conduit is a 60-inch reinforced concrete pipe 6 miles in length which conveys water by gravity to the city.

Cities which have pumping stations located on the banks of streams or lakes which have widely fluctuating water levels sometimes use suction pipes which may be raised or lowered as required. The intake assembly under those circumstances is provided with flexible joints and suitable gate and check valves.

A river intake may consist of a concrete structure placed on the river bank to form a well and protect the end of the suction pipes. The openings in the concrete wall leading to the well may be protected by bars to form a coarse screen. The intake may also include Link Belt or other types of automatically cleaned finer screens to exclude fish, leaves, twigs, and other debris. If the water level becomes very low a low diversion dam may be constructed to divert the water in the stream bed to the intake and insure that the suction pipe will be covered. This is the present arrangement at Austin, Texas.

The former intake at Austin was of another type—the infiltration gallery. This consists of slotted or perforated boxes or pipes buried in the gravel or sand of the river bed or beside the river and well below the water level. Water seeps into the gallery or pipe and thence into the suction pipe which is also perforated and enclosed in the gallery. The water so obtained has had some filtration and is therefore less turbid than water taken directly from the river.

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Chapter III

SANITATION OF SURFACE SUPPLIES

By W. E. Roberts

Sanitary Engineer

It may be taken as an axiom that all surface water will show pollution when tested bacteriologically. Therefore, it is a necessity that surface water be treated before it is made available for human consumption. Treatment, however, does not eliminate the necessity of guarding against excessive pollution or heavy contamination of the water with the organisms of the water-borne diseases, typhoid fever, the paratyphoids, and dysentery. If we take the logical stand that water should be surrounded by all possible safeguards, we must begin by preventing, so far as practicable, the entrance of disease germs into the raw water. No operator wishes the difficulties and responsibility of turning a sewage or near sewage into drinking water. Furthermore, there is always the possibility that some defect in operation of the water treatment plant may temporarily reduce its normal efficiency and a heavy pollutional load upon it would then be serious. This chapter outlines the safeguards that may be applied to impounding reservoirs and their watersheds.

Patrolling.—An impounding reservoir or lake should be surrounded by an all-weather road built on about the 10-foot contour above the high-water level. The road will be a means for adequate patrolling and inspection of the watershed, both night and day, if necessary, in addition to providing a recreational drive. The area between the road and the water's edge should be kept clear of under-brush and debris and no camps or picnic grounds should be allowed in the area. A sufficient number of attractive signs should be posted along this drive calling the citizen's attention to the fact that this is his water supply and that he is being protected by adequate regulations and precautions and asking him to do his part by conforming to them. A sanitary officer should be appointed with full police power to enforce the regulations. In small towns the water works operator or superintendent could serve in this capacity. When the area around the lake is used for park purposes and recreational activities, all park officers should be thoroughly familiar with the sanitary rules and regulations and instructed rigidly to enforce them. The municipality, public service company, or water board should own the land for at least 1000 feet from the water's edge. Authority should be obtained through the state laws and city ordinances to allow complete sanitary supervision of the property, for 5000 feet beyond the reservoir, and for all the branches, streams, and inlets tributary to it.

SEWAGE AND EXCRETA DISPOSAL.—All municipalities or villages above the supply must have adequate sewage treatment plants, approved by the state department of health. Such plants should produce a stable effluent and be provided with a final chlorination unit. Industrial plants producing sewage and other liquid wastes must also comply with this requirement. Installation of septic tanks should not be permitted within the 5000-foot police zone around the water's edge unless approved by the local and state health departments. The installation should be provided with an adequate sub-surface tile disposal field in order that none of the effluent will get into the water supply. Daily inspections should be made by the lake sanitation officer of all such installations.

For excreta disposal systems not using water carriage, the pit toilet, preferably of the concrete slab type, is by far the most satisfactory method, especially in the aforesaid police area. This type of installation has the advantage of low cost of construction and easy maintenance. It is fly tight and water tight and is practically odorless when properly constructed. For construction methods see bulletins of the Texas State Health Department. The vault-type privy, once in general use, is now becoming obsolete. It has the important disadvantages of difficulty in cleaning because the contents become liquid and in addition fly and mosquito breeding are very likely to occur. Chemical toilets, when properly installed and operated, give satisfactory results but are usually accompanied by some odor, and the installation costs are comparatively high.

GARBAGE DISPOSAL.—Garbage disposal does not usually represent a very difficult problem in watershed sanitation unless camping and picnicking are allowed. Most property owners in the police area will cooperate to the extent of constructing a small incinerator in their yards if a sketch or detailed instruction sheet is left with them by the lake sanitation officer. If camping or picnicking are allowed a regular system of garbage collection must be maintained, either by a licensed contractor, by water department employees, or by the city garbage collection forces. Usually a small charge is made to campers for the service in order to defray expenses. At the picnic grounds a sufficient number of covered garbage cans should be furnished and these should be emptied frequently.

ANIMALS.—If difficulties are encountered in keeping live animals off the 1000-foot strip of watershed property, an animal pound may be maintained and all animals should then be caught and impounded. A charge can be made for owners to redeem their property.

Provision must be made for the removal of all dead animals immediately from the lake and lake property as soon as located by the patrolling personnel. The carcasses should be removed to a point at least 1000 feet away from the lake and burned or buried. All dead animals in the entire police area must be promptly removed, burned or buried.

SUPERVISION OF RECREATION.—Since it is, in most instances, impossible to prohibit recreational activities upon a watershed, they should be limited, regulated, and properly supervised. Hunting and fishing should be restricted to the water edge and to piers. Boating may be allowed as long as no mis-use of this privilege is discovered. It is a good practice to permit no boating within half a mile of the water intake. Entrance into the prohibited water area may be prevented by placing floating booms. If camps are allowed, each must be provided with an approved excreta disposal system and arrangement must be made for garbage collection and disposal. As previously indicated, no camp, picnic ground, or barbecue pit should be located between the roadway and the water's edge. All public picnic grounds, barbecue pits, shelter houses, and fishing or boating piers must be provided with comfort stations, in each case located across the road and employing an approved method of excreta disposal. Swimming should not be allowed in any public water supply.

CHAPTER IV

GROUND WATER SUPPLIES

By Clyde R. Harvill *

Sanitary Engineer, Water Department, Houston, Texas

The fact that 80 per cent of the 684 public water supplies in Texas are obtained from wells indicates the importance of ground water as a source of supply for municipalities. Ground water supplies have certain advantages over surface supplies. They are: production of water of more uniform character and relatively free from harmful bacteria by comparison to surface supplies; a smaller capital investment in construction and equipment; cheaper cost of production. The disadvantages of ground water include: its frequently high mineral content; the difficulty of obtaining adequate supplies in some areas; in very deep wells, the high temperatures which make the water undesirable for such cooling purposes as air conditioning and other heat absorbing uses; where wells are of an unusual depth, the cost of production may exceed the cost of treating and pumping a surface supply.

In some areas special difficulties with well supplies arise because of the excessively high alkalinity of the water and the presence in it of disagreeable gases, such as hydrogen sulfide. Most of the well supplies in Texas, however, are reasonably satisfactory for domestic and general industrial use. Within the last few years attention has been drawn to the presence of fluorides in some ground waters as it causes injury to the teeth of young children. (See p. 2.)

Ordinary and Artesian Supplies.—The ground water is made up of that part of the rainfall which percolates into the soil and reaches the zone of saturation. If there is a considerable depth of pervious material beneath the ground surface with an underlying impervious stratum, a non-artesian water table will be formed as shown in Fig. 8. Such bodies of underground water usually are not very deep and are merely sources of supply for shallow wells. Exceptions occur in some areas, however, as parts of the Texas Panhandle, where in places wells less than 200 feet deep in the sands and gravels of the high plains deposits yield more than 1000 gallons a minute. In some localities shallow gravel formations in old river beds are developed for city water supply. The water level in wells where there is a water table of this type does not rise above the level at which it is struck.

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*The author wishes to acknowledge the valuable assistance of Mr. Walter N. White, Senior Hydraulic Engineer, U. S. Geological Survey, in reviewing and checking this chapter.

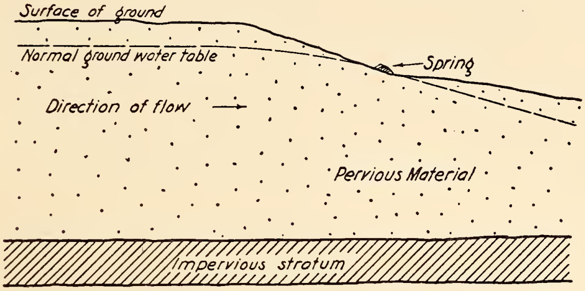
Surface of ground
Normal ground water table
Spring
Direction of flow
Pervious Material
Impervious stratum

FIG. 8. Shallow Ground Water Showing Water Table.

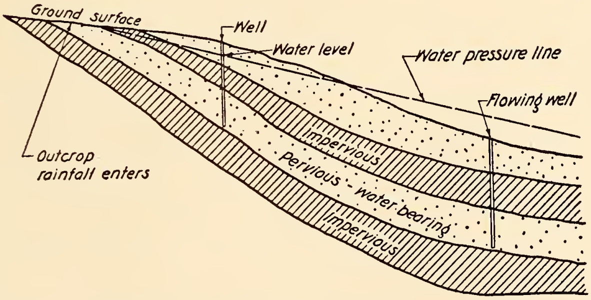
Ground surface
Well
Water level
Water pressure line
Flowing well
Outcrop rainfall enters
Impervious
Pervious - water-bearing
Impervious

FIG. 9. Diagram Illustrating Artesian Water Conditions.

Should there be at the surface, or just beneath the top soil, an outcrop of permeable material which dips beneath the surface, and provided also that the permeable material is overlain and underlain by impervious strata, artesian conditions will be set up. It will be seen in Fig. 9 that the water-bearing material is much like a sloping pipe and when it is tapped by a well the water will rise in the well to a height which depends upon the elevation of the outcrop above the well and the head lost by friction as the water moves through the water-bearing formation from the outcrop to the well. If the hydraulic head in the water-bearing formation is above the level of the ground, a well that penetrates it and is properly constructed will flow. Sand, gravel, sandstone, cavernous limestone, and fissured materials are the principal water-bearing materials.

CONSIDERATIONS AFFECTING YIELD OF WELLS.—In any locality the amount of water that a water-bearing formation will yield to a well depends chiefly on the thickness of the formation and the size and arrangement of the interstices or voids in the formation which determine its permeability. The average amount of water that can be safely withdrawn annually from the underground reservoir in the formation depends upon the average annual recharge to the reservoir from rainfall and streams, and the capacity of the formation to transmit water from the outcrops to the wells, which in turn, depends upon the permeability and thickness of the formation and the hydraulic gradient or head available to cause flow in it. In practice, all of these quantities are very difficult to determine.

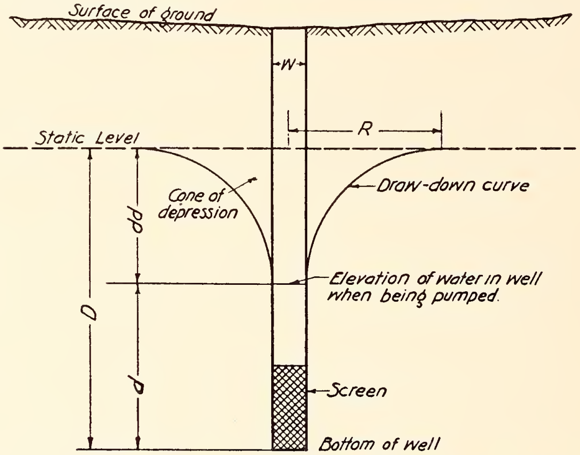

FIG. 10. Diagram Illustrating Hydraulics of a Non-artesian Well.

Both particle size and actual void space are important. Clay is as porous as sand, or more so, but the pores are so small that reasonable heads will not force water through it. Hence clay will not yield water in material quantities to wells. Coarse clean sands and gravels and some limestones, on the other hand, readily yield their waters.

Certain terms used in discussing the hydraulics of wells must be defined. They are also illustrated in Figs. 10 and 11. The height to which water will rise in a well when not pumping is known as the static level. When pumping starts, the water level drops and this decline below the static level is known as the drawdown, *dd* in the figures. When pumping an ordinary water-table well there is also a decline in the water table outside of the well for some distance *R*, which is known as the radius of the circle of influence. This depression in the formerly saturated material is known as the cone of depression. Under artesian conditions similar results occur with pumping, except that it is the pressure in the water-bearing stratum that is reduced outward to the edge of the circle of influence. When pumping from a water-table well is stopped it may require days or even weeks for the water to rise to the original static level, since the water must percolate back into the dewatered section. On the other hand, under artesian conditions, it may require only a few minutes for the pressure to be reestablished to, or almost to, the static level. The total lift in the

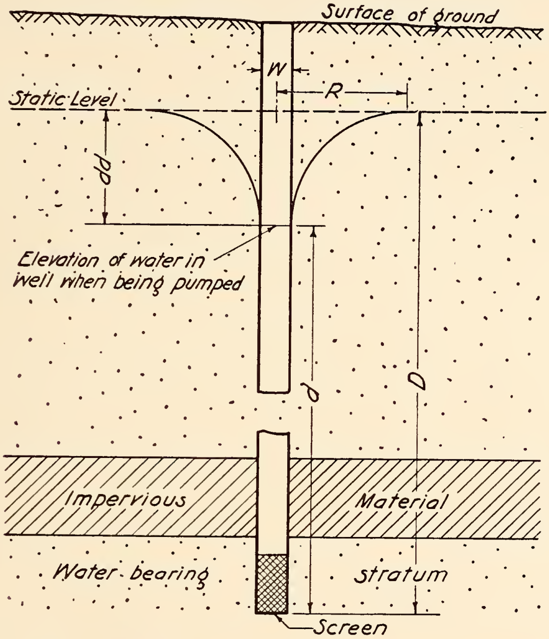

FIG. 11. Diagram Illustrating Hydraulics of an Artesian Well.

well is the distance *D*, but the total head pumped against will be made up of ~~*D*~~ dd, plus the friction head in the pump and pump discharge pipe from the drawdown point to the ground surface, plus any additional head required to lift the water above the ground.

The location of wells for a public supply may have an important effect upon their yield. If it is desired to obtain a large amount of water from a formation by means of a number of wells it is usually advantageous to locate them in a line perpendicular to the direction of the underflow. This can be determined by means of a hydrologic map on which the static water levels in existing wells are plotted, after being referred to a common datum, and lines or contours are drawn connecting the points of equal or approximately equal elevations of water levels. The movement of the water will be in a direction approximately at right angles to the contours. The line of wells, therefore, should be parallel to the contours. Under natural conditions, before heavy pumping is started, the underflow in stratified formations usually is in the direction of the dip. Before locating wells in such formations, therefore, it is important to determine the direction of the dip.

Consideration must be given to the spacing of the wells. If the wells are too closely spaced, the cones of depression of two or more wells will overlap and the wells will suffer a mutual loss in head. Thereby the total lift required to raise the water to the surface will be increased, and, of course, the pumping cost will also be increased. If practicable, heavily pumped wells which draw on the same water-bearing strata should be spaced at least one-fourth of a mile apart, one-half mile is better, to avoid excessive interference. The radii of the cones of depression, and the drawdowns in the wells are related to the amount of water pumped, the porosity and size of the particles in the material, diameter of the well (to only a small extent) and the thickness of water-bearing material penetrated by the well. The mathematical relationships of these factors are given in the standard water works texts. It should be emphasized here, however, that increasing the diameter of the well has only a small effect upon its yield. Doubling the diameter, for example, may only increase the yield 15 to 30 per cent.

WELL CONSTRUCTION

Construction of wells is a very complex process which should be carried out by competent well drillers. It is not the purpose of this chapter to acquaint the reader with the details of well drilling methods but merely to indicate in a general way some of the procedures followed and more especially the precautions that must be taken to insure a well that will yield a water sufficient in amount and free from contamination or pollution by surface water, shallow ground water, or other undesirable matter. The water plant operator should, however, be competent to advise city authorities as to the specifications which will insure a satisfactory well and he should be able to recognize and solve the problems of maintenance and operation that he will meet.

DUG WELLS.—These wells are usually of shallow depth and vary from a few to many feet in diameter. Since such wells are especially subject to contamination by surface water they must be very carefully protected. This can be done by the use of metal casing, concrete walls, vitrified tile pipe, concrete pipe, or double brick walls. This casing should be seated securely in an impervious formation wherever possible. Where an impervious formation does not occur, the protection to the supply is increased by extending the casing as far as practicable below the water table and wherever possible at least 10 feet below the lowest level of the water table. The casing should extend at least 7 inches above the pump room floor or the surrounding ground surface and it is desirable to extend it more than the minimum above the ground surface. A concrete apron or ring should extend around the outside of the casing at least 12 inches in order to divert water from the well. A tight cover over the top of the well is necessary. The pump should be placed on the well cover in such a manner that waste water from the pump will not return to the well. The pump base should also be sealed so that rodents, insects, rainwater, etc., can not enter the well. After the well has been completed, it should be disinfected with some form of chlorine in order to destroy any contamination that may have entered the well during construction (see p. 48). This type of well is not generally used for public supplies except in areas where comparatively small quantities of water are required.

DRIVEN WELLS.—When water is found at depths ranging from 20 to 70 feet, driven or tubular wells may be used if the quantity and quality of the water are satisfactory. These wells are made by simply driving a metal pipe to the water-bearing stratum, the pipe acting as the permanent casing. With this type of well special precaution should be taken because the strata penetrated are likely to show contamination. The well should be protected from surface waters by having a well top of concrete with an apron; the well pump should be properly sealed; and the well surroundings should be banked and tamped to divert surface waters.

DRILLED WELLS.—To the municipal water plant operator the drilled well is by far the most important type. While the well is being drilled a careful log should be kept recording the depth, thickness, and characteristics of each formation that is encountered. The log should be carefully preserved for future use. Various drilling methods are used and these will be described very briefly, together with certain important features of construction.

The standard method. The standard method consists of a standard rig or cable tool which is used to drill through hard formations. It essentially consists of prime mover, derrick, wheels and spools for cable, and a walking beam which raises the bit and allows it to drop into the hole. The well is deepened by the drill bit striking the formation and the broken material is removed by means of a bailer. The drill bit is of a size to permit casing to be introduced into the well after it has been completed.

The rotary method. This method is the one most widely used in drilling Texas water wells. The rig consists of a derrick, prime mover, draw works, rotary table, and mud circulation pump. The draw works include reels equipped with brakes and clutches which allow transmission and control of the power from the prime mover to the rotary table. A drive chain or shaft from the draw works turns the rotary table. The rotary table is located over the well and the drill stem which has the bit on the bottom is turned to give an auger effect.

The cutting bit, either of the rock type or fish-tail shape, wears away the rock or other material by downward pressure and grinding action. The drill stem is hollow and drilling mud is pumped into the drill stem at the top and allowed to discharge near the cutting surface of the bit. This serves to keep the bit cool and return the cuttings to the surface and to plaster the sides of the drilled hole to prevent caving. As the drilling mud may impede or cut off the flow of water into the well, great care is necessary in using the rotary drills, and especially where the depth to the water-bearing formations is unknown.

WELL CASING.—The well casing may be placed while drilling to prevent caving but the usual procedure is to drill the well to the water-bearing strata and then, if the chemical test is satisfactory, the casing is placed. All water wells should be cased at least to the top of the water-bearing formation and preferably to the bottom of the well. Where the latter is practiced, the screens are located opposite the water-bearing formations and blank casing is used in the other portions of the well. This prevents undesirable water from entering the strata which are producing desirable water.

In choosing the well casing the depth, diameter, type of formations penetrated, and corrosiveness of the water encountered should be considered. The minimum standard weights for steel casing, which is the material in general use, should not be less than as follows:

Outside Diameter, Inches	Inside Diameter, Inches	Weight, in Pounds per Lineal Foot
13⅜	12.61	54
13	12.28	50
8⅝	7.92	32
7	6.33	24
6⅝	5.98	22
5¾	5.19	17
4¾	4.08	16

If the water is especially corrosive the casing should be heavier. Cast-iron pipe, with threaded couplings, in sizes to 12 inches, is being used in some areas where highly corrosive water is encountered above the water-bearing formation that is tapped.

The casing should be carefully placed and great care exercised to make the joints tight, especially where the casing size decreases. Within the last few years it has been considered good practice to cement the entire portion of the casing from a point immediately above the top of the water-bearing formation to the surface of the ground. The former practice of using drilling mud or clay to fill the annular space between the outside of the casing and the drilled hole has been found unsatisfactory in many instances.

The rapid development in the drilling of oil wells within the last few years has made services of companies specializing in the several phases of well drilling available for water well drilling. This includes an alignment test to verify that the drilled hole and casing are sufficiently straight to permit the satisfactory operation of a centrifugal pump. Also, the development of the electric method for the logging of wells has resulted in additional data being available on the types of formation in a well which supplement the driller's log. It is now possible to make drill-stem tests of formations where the quality of the water is unknown and this test also furnishes a sample of the formation which can be studied as to the particle size, porosity, and other factors that govern in deciding upon the tapping of a particular formation. The water secured in the drill stem test can be readily analysed to obtain its chemical characteristics. The specialized work of cementing wells will be discussed below.

CEMENTING WELLS.—The casing in the well is cemented in place to prevent undesirable water from entering the strata from which water is obtained and to protect the casing from corrosive water and thereby prolong its useful life. The usual procedure is to place at the bottom of the first joint of well casing a wooden plug which has a hole in the center of a proper size to permit the drill stem to enter and seat. The casing is then made up and placed into the well to a point immediately above the first formation from which water is to be withdrawn. After the casing is in place the drill stem pipe is placed inside the casing and extended to the hole in the wooden plug at the bottom of the casing. High early strength cement is then pumped down through the drill stem and allowed to return around the outside of the well casing to the surface of the ground. This effectively fills the annular space between the outside of the well casing and the drilled hole. While this work is being done it is necessary to proceed as rapidly as possible because cement of this type sets up within a short period of time and should the work be interrupted the cement will set up in the pump and drill stem pipe and the job will not be effective. After the cementing has been completed the wooden plug at the bottom of the hole is drilled out and the screen and additional well casing are placed in proper position in the lower portion of the well. The space between the upper portion of the well casing and the lower portion in which the screen is made up is then cemented, lead-sealed or graveled into place. In instances where a large casing is used at the top portion of the well, in order to permit the installation of a centrifugal type pump and the well proper is of a smaller diameter, the lower portion of the casing is extended into or overlapped a distance of at least 100 feet and the space between the larger and smaller casing is filled with gravel.

Experience has shown that the cementing of wells usually requires specially designed equipment and it is usually considered good practice to have this work done by companies specializing in this type of work. If material other than high early strength cement, as a concrete mixture of cement, sand, and gravel is used it has been found that it will stratify and the job will not be satisfactory. In other words, the cementing mixture is of Portland cement and water only. The cement should be allowed about 72 hours to set.

THE SCREEN.—The purpose of the well screen is to exclude excessive amounts of sand and to permit an ample quantity of water to enter the well with a minimum loss of head. Many types of well screen are on the market. In general, they include the wire-wrapped, slotted openings, and perforated pipe. Well screens are to be had in bronze, brass, stainless steel, or galvanized materials. The former three are corrosion-resistant and are those in general use at the present time. The galvanized screen is rapidly becoming obsolete due to the development of better methods of well construction. Concrete screens have also been used successfully in certain areas.

The most important feature of the screen is the size of the opening, which should be small enough to exclude coarse sand from entering the well proper. The best way of determining the proper size of screen opening is to take representative sand samples from the water-bearing formation and dry it. The sand is then screened through standard sieves and these data furnished the screen manufacturers. It is considered good practice to make the screen opening of a size that will permit about 75 per cent of the dry sand to pass through the opening. The 25 per cent of dry sand that would be retained on this opening would probably be more than 50 per cent of the sand when it is wet. The screen manufacturers, in general, can be depended upon to recommend proper size openings for their respective screens and their recommendations should be followed. Within the last few years it has been found that wells producing not to exceed 2 ounces of dry sand per 100 gallons of water are generally satisfactory for public water supplies.

THE GRAVEL-WALL WELL.—This type of well is designed to conform with natural sub-surface conditions and its construction varies in different areas. It is especially adaptable for areas where the water-bearing formations consist of fine sands. In most cases, a test hole is drilled to the depth at which the well is to be completed and from the information gained the design of the permanent well is determined. Usually a casing 12 to 24 inches in diameter is set from the ground surface to the top of the uppermost water-bearing sand from which water is to be admitted into the well. The casing is cemented in place by forcing high early strength cement through the inside of the casing until it returns on the outside of the casing to the ground surface. This cement is then permitted to set for approximately 72 hours, after which the cement plug at the bottom of the casing is drilled through and the well proper drilled to a size sufficient to permit the introduction of the well casing. Each stratum from which water is to be obtained is enlarged to a diameter of 20 to 36 inches by means of expanding under-reamers. When this work has been completed to the predetermined depth of the well the liner, consisting of well strainers or screens and blank pipe, is set in the finished portion of the hole below the upper well casing. This liner of blank pipe is of sufficient length to lap a considerable distance into the larger casing, usually about 100 feet. Selected graded gravel of sizes to exclude the sand found in the water-bearing formations is then introduced into the under-reamed portions in each of the water-bearing formations through a pipe on the outside of the liner by means of a hydraulic pump and gravel machine. The gravel thus introduced provides a filter bed to exclude the large sand particles around each of the screened areas. This gravel is also placed outside the blank casing to the point where it overlaps into the larger casing. This effectively fills the annular space between the well casing proper and the drilled hole, and prevents the casing from shifting. The gravel in the overlapped portions of the large and small casings provides a reserve gravel supply for the well.

The advantages of the gravel wall type well include: a larger production due to the increased diameter in the producing strata; decreased operating cost due to free inflow of the water in the strata and consequently less drawdown in the well; the elimination of fine sand because of decreased entrance velocity of the water through the gravel filter bed; a longer useful life of the well by reason of the use of larger screen openings which do not readily become encrusted or clogged.

DEVELOPMENT AND TESTING.—Development of a well consists of agitating the sand in the vicinity of the well screen to dislodge the fine particles and drilling mud. This is accomplished by swabbing, or surging, which forces the water outward through the screen, and by pumping. The development pumping may be done with a regular well pump or by means of the air-lift. The output of the well should be measured by means of a weir, orifice, or other measuring device and the drawdown noted for each production range. Generally speaking, the drawdown is proportional to the yield. That is, if a well yields 100 gallons per minute with a 50-foot drawdown, it will usually yield 200 gallons per minute if the pump is powerful enough to cause a 100-foot drawdown. The test, however, should establish the drawdown and its accompanying yield and a pump of such capacity should be installed so that the well does not produce excessive quantities of sand. In other than gravel-wall wells the excessive pumping of wells may result in the formation of a cavity which may cave and ruin the well. Excessive quantities of sand in the water will cause undue wear on the screen, damage the pump and other equipment.

SANITARY PRECAUTIONS IN WELL CONSTRUCTION.—The precautions should start with the location of the well. The site should not be subject to overflow. The wells should be located on a site higher than the surrounding ground surface if possible. A well should be located at least 150 feet away from any privy, cess pool, sewer or soil pipe through which sewage is transmitted. This horizontal distance should apply only in areas where ideal conditions exist and greater distance should be required where local conditions demand such. All sewers within a horizontal distance of 50 feet from the well should be of cast-iron pipe with tested water-tight leaded joints.

The well casing should extend at least 7 inches above the ground surface and in some areas at least 24 inches. The opening between the top of the casing and the pump base or discharge pipe should be screened to prevent the entrance of insects or animals. Older type wells sometimes have the pump placed in a pit over the well. The dangers of seepage water entering the well with this type of installation are obvious. Modern installations eliminate the necessity for the pit by the discharge pipe being above the ground surface. Where pits exist around wells they should never be drained to sewers as epidemics have resulted by clogged sewers backing sewage into the pit where it entered the well. Pits should be drained by small hand or mechanically operated pumps.

The slush pit used in the construction of a well should not be in a stable yard or chicken yard. The workmen should be provided with sanitary conveniences which should consist of a connection to a sanitary sewer or an approved type pit toilet. During construction the drilling mud should be kept as free from contamination as possible. In areas where oil development has occurred the use of drilling mud from oil wells has caused difficulties.

Gravel used in gravel-wall wells should be chlorinated as it is placed into the well with a solution containing not less than 10 parts per million of residual chlorine. After the construction of a well has been completed and prior to its placement into service the well should be disinfected by means of a chlorine solution. This is usually accomplished by the mixing of high test hypochlorite or chloride of lime in water so that the solution will produce a residual of at least 1 to 5 parts per million after being placed in the well. The amount of chlorine to produce the required residual will vary according to the conditions under which the well was constructed and the character of the water in the well. The strength of chlorine solution required to produce the desired residual is found by the trial and error method as a calculated amount will be subject to gross errors. An orthotolidin testing set, for checking chlorine residuals, can be had from laboratory supply firms. The chlorine is introduced into the well at or near its bottom by means of a pipe and allowed a contact period of at least 20 to 30 minutes, after which it is removed by means of pumping. The introduction of chlorine solution at the surface of the water in a well will not effectively sterilize the entire well. After the well has been pumped until all of the chlorine solution has been removed a sample should be collected for bacteriological examination. It is considered good practice to include in the well contract the provision that the completed well will show a bacteriologically safe water before the well is accepted.

OPERATION AND MAINTENANCE OF WELLS

Operating problems of wells are mainly concerned with maintenance of yield and prevention of pollution and contamination. These problems will be discussed separately.

DECREASED YIELD.—This may be caused by one or more of a number of conditions. Heavy draft upon the water-bearing strata may have lowered the static and pumping level in the well. The static level should be checked against the original static level records to determine whether this is the case. There is of course no remedy for this condition, although the pump may be lowered, or a more powerful one installed, to increase the drawdown and lift more water.

Sand may have packed around the screen. This sometimes can be remedied by exploding blasting caps in the screened portion of the well with electricity at intervals of about 2 feet. The jar loosens the packed sand and may also dislodge material attached to the screen, as calcium carbonate or other incrusting matter.

An incrusted screen usually can not be withdrawn from a well for cleaning. In some instances the acid process may be used to clean the screen in place. This, however, should be done only under the supervision of a competent engineer or chemist thoroughly familiar with such operations. Brass, bronze, or stainless steel screens have been successfully cleaned with inhibited muriatic acid (inhibited commercial hydrochloric acid). Galvanized screens are usually a total loss if cleaned with acid. The amount of inhibited acid to be used will depend upon several factors. The approximate severity of incrustation can be roughly estimated by comparing the static level, pumping level, and recovery time of the well to that when the well was first placed in operation. The acid strength should usually be between 10 and 25 per cent of the total volume of water in the casing as calculated from the static level and pipe diameter. Enough inhibited acid is then placed in the well to make a 10 to 25 per cent solution, introduction being through a string of pipe extended to a point just above the lowest screen setting. The acid can be put into the well by either a hand or mechanically operated pump that can handle acid without failure during operation. The pump discharge should be connected to the string of pipe by either a flexible or rigid connection that does not leak. Before the work is started several boxes of sodium bicarbonate (ordinary baking soda) for neutralizing any spilled acid should be placed conveniently near the pump. Two buckets of water in each of which one box of soda has been dissolved should be easily accessible for pouring on acid spilled on the ground. The person in charge of the acid cleaning operation should insist that workmen immediately rub dry soda on any acid spots on the clothing and dip their hands into the solution bucket frequently while handling the acid. After the acid has been placed in the well 100 to 200 gallons of water should be pumped through the string of pipe before it is removed and disconnected. The length of time that the acid should remain in the well will vary according to the concentration used and the amount of incrustation to be removed, but roughly speaking, it should be from 2 to 8 hours. The pipe used for conducting the acid into the well should be removed with care as it will have acid on both the inside and outside. A stream of water should be played on the pipe as it is withdrawn and as each joint is broken a splash guard should be placed around the joint. It should be pointed out that galvanized pipe probably will be unsatisfactory for conducting the acid into the well.

The acid can be removed by reinstalling the pump and discharging the water to waste. This should continue until the pH of the water is 7.0 or more and the water should not be used until the test shows the acid has been satisfactorily removed.

PREVENTION OF WATER-BORNE DISEASES.—Keeping the well water safe requires maintenance of the safeguards already mentioned. The top of the well should be kept sealed so that no contaminating matter may enter. The waste water used for cooling bearings in some types of pumps should not be returned to the well. Plant operators should be on the alert to prevent the placing of sewers, privies and other potential dangers near the well. In Texas, nearby oil wells that are improperly cased may permit oil or salt water to enter the fresh water-bearing strata. When pumps or discharge columns are withdrawn from wells, care should be taken in the handling of this equipment while on the ground surface, and the well should be sterilized prior to placing back into service. Bacteriological tests should be made on all wells, as regularly and frequently as possible, since occasional sampling is no criterion of a safe supply. Until recently water obtained from wells, except in limestone formations, was generally considered to be the safest supply obtainable. However, the study of water-borne epidemics within the last 10 years shows that a large percentage occurred from well supplies not regularly treated. Pollution was found entering the well from local contaminating sources through openings at the top of the casing, by back-siphonage from blow-off lines to sewers, or from broken or deteriorated casings of abandoned wells in water-bearing formations. This has caused public health and water works health officials generally to safeguard well supplies by means of continuous chlorination. This does not, of course, mean that wells, known to be polluted, should not have defects corrected and that reliance be placed in chlorination only to produce a safe water but this provides a safeguard to the consumer against contaminated water until defective conditions can be corrected.

CHAPTER V

PUMPING OF WATER

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The three principal requirements of pumping equipment are reliability, adequacy, and economy. Reliability can be obtained by installing the best type of equipment in duplicate; adequacy, by securing liberal sizes; economy, by taking into account the life and depreciation, first cost, stand-by charges, interest, and operating costs.

A careful analysis should always be made before selecting the size (capacity) and type of pump for a given purpose. A pump may operate although it is not the proper size or type for the specific requirements, but under those conditions its efficiency will be low and operating cost will be high. The same statement may be made concerning many old pumps already in operation. Frequently, an engineering investigation will indicate that they are costly because of inefficiency or obsolescence and good practice would justify their replacement.

CONSIDERATIONS AFFECTING PUMP PLANTS.—Authorities continue to emphasize the fact that fire service pumping requirements, as outlined by the Texas State Fire Insurance Commission and National Board of Fire Underwriters, should determine pump installations. Some of the requirements are: dual power supply for reliability; pumps housed in fireproof structures; effective operation and maintenance. Secondary sources to supplement electric drive are generally Diesel or gasoline engines. Dual power is not required if steam equipment is the primary source of power.

Pumping capacity is recommended to be sufficient to meet maximum domestic demand combined with fire flow at the required pressure. The State Fire Insurance Commission recommends that the pumping plant be capable of furnishing 50 gallons per day per capita for domestic requirements, in addition to 60 gallons per day per capita for fire flow requirements, making a total of 110 gallons per day per capita. This requirement must be satisfied even though the two largest pumping units are out of service. It should be recognized that the amount mentioned is the minimum fire-fighting requirement, regardless of the size of the city, and presumes also that there is an adequate amount of water available at all times.

Preliminary to specifying a pump installation the maximum capacity that may be demanded of the installation should be estimated; the nature of the water should be considered, its temperature, whether it is acid or alkaline, whether it contains objectionable chemicals, gases or suspended matter, and if such suspended matters are abrasive; the average, maximum and minimum discharge head conditions, including the size of the pipe and whether the pipe system is closed or open and with fixed elevation; the average, maximum, and minimum suction head (pressure) or suction lift (vacuum), also the diameter and length of suction lines if already fixed; the service, whether constant or intermittent; type of power available for pump drive; space available for the pumps; considerations as to weight of the pumps and power units.

The pump should be of an established make. Its performance under varying conditions should be known and guaranteed by the maker. Its parts should be readily replaceable. Many water works men are misled as to the efficiency and operating costs of pumps by official tests under full-load conditions, whereas the efficiency falls off under the normal operating condition of partial loads and intermittent operation.

Pump Classification.—Pumping equipment as used for general water service can be broadly divided into two general classes, displacement and centrifugal, each of which can be subdivided into types that differ in design of details but having distinct features common to each type. Well pumps may also be of the displacement or centrifugal type, with another possibility—the air lift. The classification given below shows the common subdivision of the displacement and centrifugal types.

- Displacement
  - Piston or Plunger
    - Direct-Acting Steam
      - Single
      - Duplex
    - Crank- and Fly-Wheel
    - Power
      - Single
      - Duplex
      - Triplex
  - Rotary
    - Cam
    - Screw
    - Gear
    - Vane
- Centrifugal or Screw
  - Single Stage
  - Multistage

DEFINITION OF HEAD.—Capacity of pumps is usually expressed in terms of gallons per minute. Computation of the power required to drive a pump necessitates knowledge of the amount of water pumped and the total head pumped against. The total head includes the actual lift between the water level at the intake and the level of the elevated tank which receives the water, plus the velocity head, and the friction overcome in the process, translated into terms of head of water. Heads of water are frequently expressed as pressure in pounds per square inch.

Where water temperatures do not exceed 85 degrees Fahrenheit, the specific gravity of water is generally taken as unity and the weight of water as 8.34 pounds per gallon or 62.4 pounds per cubic foot. When the weight of water is known the pressure caused by a column of water 1 foot high obviously is 62.4 ÷ 144 or 0.433 pounds per square inch. Conversely if the pressure in pounds per square inch is known it may be divided by 0.433 or multiplied by 2.307 to find the head of water in feet.

Total head is made up of two elements: (1) the *discharge head* and (2) the *suction head* (pressure), or the *suction lift* (vacuum).

Discharge head is the pressure in pounds per square inch within the discharge (exit) side of the pump, multiplied by 2.307, to express it in feet head. This amount must be corrected to the pump center-line (plunger, piston or shaft center) as follows: (*a*) If the gauge center, or lower surface of mercury in the mercury type gauge, is *below* the pump center-line then the vertical distance in feet from the gauge center, or lower surface of mercury, to the pump center-line should be *subtracted* from the *discharge head* obtained from gauge readings in terms of feet. (*b*) If the gauge center, or lower surface of the mercury is *above* the pump center-line, then the vertical distance in feet from the gauge center, or lower surface of mercury, to the pump center-line should be *added* to the *discharge head* obtained from the gauge reading in terms of feet.

Suction head occurs where there is a pressure (positive head) existing within the suction side (inlet) of the pump. The amount of *suction head* is the pressure in pounds per square inch, multiplied by 2.307, to express same in terms of feet head. This amount must be corrected to the pump center-line as follows: (*a*) If the gauge center, or lower surface of the mercury, is *below* the pump center-line, then the vertical distance in feet between the gauge center, or lower surface of the mercury, and the pump center-line should be *subtracted* from the gauge reading in terms of feet. (*b*) If the center of the gauge, or lower surface of the mercury, is *above* the pump center-line, then the vertical distance in feet between the gauge center, or lower surface of the mercury, and the pump center-line should be *added* to the gauge reading in terms of feet.

Suction lift occurs where a partial vacuum (negative head) exists within the suction side (inlet) of the pump. The amount of the *suction lift* is determined by the suction gauge reading in terms of feet, but, if the reading is in terms of inches of mercury, then multiply by 1.134 to express same in terms of *feet lift*. This amount must be corrected as follows: (*a*) If the gauge connection to the suction side of the pump is *below* the pump center-line, then add the vertical distance in feet between the gauge connection and the pump center-line to the gauge reading in terms of feet. (*b*) If the gauge connection is *above* the pump center-line, then the vertical distance in feet between the gauge connection and the pump center-line should be *subtracted* from the gauge reading expressed in feet.

The term velocity is applied to the rate of flow of water, usually expressed in feet per second, in a pipe or other conduit. A simple conception of the calculation necessary to determine velocity, when the size of the pipe and amount carried are known, is to divide the number of gallons in a 1-foot length of the pipe into the flow expressed in gallons. For example: It is desired to compute the velocity in a 6-inch pipe carrying 8 gallons per second. The volume of any 1-foot length of pipe in gallons is equal to the square of the diameter in inches multiplied by 0.0408. In this case it is $6 \times 6 \times 0.0408 = 1.47$ gallons. The velocity will then be $8 \div 1.47 = 5.5$ feet per second.

Obviously energy is required by water to give it a velocity in suction and discharge pipes. This energy can be expressed in terms of water head in feet. The *velocity head* can be computed by squaring the velocity in feet per second and dividing by 64.4. For example: In the 6-inch pipe discussed above the velocity is 5.5 feet per second. The computation would then be $5.5 \times 5.5 \div 64.4 = 0.48$ feet. It will be seen that the velocity head is very small. Usually it can be neglected unless the velocity is very high or close computation of heads is necessary. If it is considered it must be added to the other heads.

DEFINITION OF POWER AND EFFICIENCY.—Power is the time rate of doing work. The common unit for measuring power is the horsepower. A machine developing 1 H.P. is doing work at the rate of 33,000 foot pounds per minute or 550 foot pounds per second. A foot pound of work is done when a weight of one pound is raised 1 foot vertically. Applying this to water: A pump is raising 500 gallons per minute against a total head of 200 feet. The foot pounds per minute will be $500 \times 8.34 \times 200 = 834{,}000$. Dividing this figure by 33,000 gives 25.3 as the *water horsepower*.

Electrical power is expressed in watts and kilowatts, the latter being 1000 watts. Horsepower can easily be transferred into kilowatts by multiplying by 0.746. Conversely, since a kilowatt is equal to 1.34 H.P., kilowatts may be transformed into horsepower by dividing by 1.34. In the above example the kilowatts of electrical power would be $25.3 \times 0.746 = 18.9$.

The *water horsepower* of a pump, expressed as a definition, is a measure of the rate at which energy is required to be supplied to the water by the pump. It may be expressed in specific terms as the number of pounds of water pumped per minute multiplied by the total head in feet, and this amount divided by 33,000. The *mechanical efficiency* of a pump is the ratio or proportion of the water horsepower to the horsepower required to drive or operate the pump. *Brake horsepower* is the actual horsepower required to be applied to the pump shaft to drive the pump, and is determined by dividing the water horsepower by the mechanical efficiency. The *over-all efficiency* of a pumping installation is the water horsepower divided by the horsepower applied to the motor or other prime mover which drives the pump.

DISPLACEMENT PUMPS.—The *direct-acting steam pump* is a reciprocating unit in which the steam piston is directly connected to the pump rod of the pump piston or plunger and the length of the stroke is regulated by the action of the lost-motion adjustment of the steam valve and also by the adjustment of the cushion valves of each steam cylinder. This type of pump may have one water piston (single) or its equivalent single or double-acting plunger, or it may have two water pistons (duplex) or their equivalent single or double-acting plungers. Double-acting pistons or plungers discharge water on both the ''forward'' and ''back'' strokes.

Direct-acting steam pumps have the advantage of low first cost, durability, flexibility, and ability to operate against high heads.

Efficiencies are high, usually from 40 per cent in 3-inch to 4-inch length of stroke to 80 per cent with a stroke of 2 feet or more. The disadvantages include necessity for frequent adjustments, inability to pump sandy water successfully, relatively great weight and size, comparative complication, and usual necessity for priming. A vacuum chamber is essential on the suction side and an air chamber on the discharge side of the pump in order to equalize flow in the suction piping and eliminate pulsations in the discharge piping.

Crank-and-flywheel pumps are reciprocating units with a crank shaft on which a flywheel is mounted to store energy during the first part of the stroke, imparting the stored energy to the water piston or plunger rod during the latter part of the stroke, after the steam has been cut off in the steam cylinder. The length of the stroke is fixed by the throw of the main crank, and the length of stroke is two times the distance from the center of the crank shaft to the center of the crank pin.

Power pumps are reciprocating units driven by power from an outside source applied to the crank shaft of the pump, and are subdivided into (1) *single,* having one water piston or its equivalent single or double-acting plunger, (2) *duplex,* two water pistons or their equivalent single or double-acting plungers, and (3) *triplex,* having three water pistons or their equivalent single or double-acting plungers.

Crank-and-flywheel types, and also the steam-driven power pumps, have the advantages of durability, operation against high heads, a uniform flow from the multi-cylinder types, high efficiency, less clearance space in the pump cylinder, and are considered the most efficient type for heads over 300 feet. The efficiency does not vary greatly with varying heads. The disadvantages include high first cost, limited flexibility, great weight and size, operation at slow speed, necessity of priming, and inability to pump sandy water successfully. There is also a possibility of damage if a valve in the discharge pipe is closed, unless an automatic relief is installed.

Rotary displacement pumps are of the belt, geared, or direct drive types, with a casing containing the rotating elements. These consist of cams, screws, gears, vanes, or some modification of these types. The diameter of the pump discharge determines its nominal size, but does not fix its capacity. Rotary pumps are similar to displacement pumps in many respects. They are of special value in pumping oils or other viscous liquids since there is better lubrication of the rubbing surfaces and less likelihood of leakage. They may be used for heads up to several hundred feet but are best adapted to low or moderate pressures.

The principal advantage of the rotary pump is the substitution of rotation for reciprocation, which allows greater speeds with reduction of pump size for same capacity. The disadvantage is that they tend to become inefficient with wear and slip then becomes excessive. Even when new they may show too much slip on the one hand or excessive mechanical friction on the other.

CENTRIFUGAL PUMPS.—The centrifugal pump consists of an impeller rotating in a casing. Water is drawn through the suction pipe into the center or eye of the impeller and the curved vanes of the rapidly moving impeller throw it outward through the action of centrifugal force. In the process the water is given a high velocity and a correspondingly high velocity head. A large part of the velocity head is converted into pressure head in the casing and the water will leave under this pressure to enter the discharge pipe. The velocity of the water will depend upon the impeller velocity. Hence, since the amount of water pumped depends upon the velocity through the pump, the amount of water pumped will increase in the same ratio as impeller speed. The head generated by the pump depends upon the velocity head of the water and this, it will be remembered from a preceding paragraph, depends upon the square of the velocity. Hence the head varies as the square of the velocity. By a theoretical analysis that will not be given here, it is possible to show that the power required varies as the cube of the impeller velocity. It is considered, of course, that the impeller diameter remains the same. These relationships, which hold very closely in practice, may be expressed as: Q varies as N; H varies as N^2; P varies as N^3. Q is the amount of water pumped; N is the pump speed in revolutions per minute; H is the head in feet; P is the power.

Example: A centrifugal pump is pumping 90 gallons per minute against a head of 180 feet at a speed of 1400 revolutions per minute. The power required is 7.45 H.P. If the speed is increased to 1800 revolutions per minute compute the amount of water pumped, the head and power required. The impeller diameter is unchanged. The computation in each case is a proportion. The new Q will be $(90 \times 1800) \div 1400 = 116$ gallons per minute. The new H will be $(180 \times 1800 \times 1800) \div (1400 \times 1400) = 275$ feet.

The new P will be $(7.45 \times 1800 \times 1800 \times 1800) \div (1400 \times 1400 \times 1400) = 15.8$ H.P.

It will be seen that there is an intimate relationship in centrifugal pump operation between head, speed, and power. If head is increased without changing the speed, the output will decrease. It is, in fact, possible to add such head that the impeller merely turns around in the water without causing discharge. This is known as the shut-off head. It is also the head that is generated, as shown by a pressure gauge, if a valve in the discharge pipe is closed while the pump is running.

The efficiency of centrifugal pumps varies at different speeds and heads. Manufacturers have the characteristics of their pumps and a pump should be chosen that will give good efficiency at the head under which it is to operate and for the output required. If there will be wide variations in head, which is not uncommon in water works practice, a pump should be chosen that will not vary greatly in efficiency at the different head ranges. Efficiencies vary with pump sizes, larger pumps being more efficient than small ones. In practice the efficiencies range from 40 to 80 per cent, with 60 per cent as an average.

Centrifugal pumps are classified in various ways. The *single stage type* has one impeller, but it may have a single or double suction entrance. The *multistage type* has two or more impellers arranged so that the discharge from one enters the eye of the next. This type is used for high heads. The *volute type* has the casing arranged to increase in cross section to the discharge pipe. In the *turbine type* the casing does not increase in size but the water moves from the impeller to the casing between fixed vanes. The impellers of the various types may be radial flow, axial flow or a combination. Pump sizes are given as the diameter of the discharge pipe.

Centrifugal pumps have a number of advantages. They are simple, requiring no valves within the pump, no internal lubrication, and no vacuum or air chambers on either suction or discharge. They are low in first cost, require very little room for their capacity and they are practically noiseless. If a valve on the discharge pipe is closed the pump will not be damaged. The disadvantages are: the effect of head upon efficiency and output, and the necessity for careful priming before the pump can be started. They cannot be used against extremely high heads as can the displacement pumps.

RECIPROCATING VERSUS CENTRIFUGAL PUMPS.—Where moderate heads are encountered, very little space is available, first cost must be kept low, and only moderately skilled attendance is to be expected, the centrifugal pump is preferable. This type of pump is easily connected to electric motors and Diesel engines in the smaller installations, and to steam turbines in the larger plants. For these reasons the centrifugal pump is the favorite for municipal water works. On the other hand, where extremely high heads must be dealt with, where highly skilled attendance will be given, and the economics of the situation justify higher first costs to obtain high efficiency, the reciprocating pump may be justified.

THE SUCTION PIPING.—The allowable suction lift between the pump and the source of supply depends upon several factors. The barometric pressure varies somewhat from time to time but it is most dependent upon altitude. The higher the elevation above sea level the lower is the barometric pressure and the lower will water rise when a pump creates a suction. The water temperature also affects the rise since the pressure of water vapor in the suction pipe operates against the suction lift. The greater the temperature the greater the vapor pressure and the lower the allowable lift. Also the efficiency of the pump affects the lift. Table III combines these factors to show the maximum permissible suction lifts for different elevations and water temperatures. Of course, there must be a further reduction for friction losses caused by a suction pipe that is long and has many elbows or turns.

TABLE III.—MAXIMUM SUCTION LIFT IN FEET

Elevation Above Sea Level	Temperature of Water in Degrees Fahrenheit										
	60	70	80	90	100	110	120	130	140	150	160
0	22	20	17	15	13	11	8	6	4	2	0
2,000 ft.	19	17	15	13	11	8	6	4	2	0	
4,000 ft.	17	15	13	11	8	6	4	1	0		
6,000 ft.	15	13	11	8	6	4	2	0			
8,000 ft.	13	11	9	6	4	2	0				
10,000 ft.	11	9	7	4	2	0					

At high water temperatures vapor pressures become so high that the pump must be placed *below* the water level to cause flow in the suction pipe. Table IV gives the minimum heads required between the water level of the source and the pumps for proper operation. These heads must also be increased for long suction pipes.

TABLE IV.—MINIMUM SUCTION HEAD IN FEET

Elevation Above Sea Level	Temperature of Water in Degrees Fahrenheit										
	110	120	130	140	150	160	170	180	190	200	210
0						0	3	5	7	10	12
2,000 ft.					1	3	5	7	10	12	15
4,000 ft.				1	3	5	7	10	12	14	
6,000 ft.			1	3	5	7	10	12	14	16	
8,000 ft.		0	3	5	7	9	12	14	16		
10,000 ft.	0	2	4	7	9	11	14	16	18		

Where suction lift prevails, arrangements to prime the pump are necessary. In displacement pumps water connection from the discharge to the plunger chambers is convenient, but if the pump suction is equipped with a foot valve, then a relief valve is necessary on the suction to protect low-pressure fittings. Centrifugal pumps are usually provided with an air, steam, or water-operated ejector connected to the top of the pump case.

The suction piping should be as short and direct as possible and of such a diameter that the velocity in it will not exceed 4 feet per second. The suction pipe preferably should be larger than the discharge pipe. Concentric reducers are undesirable when reducing suction pipe diameter to pump suction diameter. An eccentric reducer should be used when connecting directly from the pump suction piping, or if to a pipe fitting, the fitting opening should be of the same diameter as the suction pipe. The short "throw" of the eccentric reducer fitting should be on the top.

If it is necessary to use an elbow or bend horizontally in the suction piping, it should be located at a distance from the pump suction connection, so the flow of water will tend to be equal and not along one side of the suction connection to the pump.

A suction pipe should never be level, but in order to avoid air pockets, should slope upward toward the pump from the source of supply. Good practice requires that it be tested under pressure regularly for leaks.

Noise in a centrifugal pump is an indication of impact. Air, or other gases present in the water, or derived from air leaks in the suction piping or in the pump packing, may cause the noise. If not so caused it is an indication of poor pump design, which causes separation of air and gases from the water and, incidentally, causing wear or pitting of the impeller and pump casing.

Vacuum chambers should be installed where reciprocating pumps are used, especially those of short stroke, and if suction lines are long or high suction lift conditions exist. On pumps of the end suction type, a tee can be arranged with the run vertical and the side opening connected to the pump suction connection, the vacuum chamber being located on the top of the tee. Water entering the lower opening of the tee, changing direction to horizontal in entering the pump, will permit the chamber above to exert the desired effect of equalizing the flow to the pump.

Pumps of the side suction type are generally arranged to connect suction to either side of the pump. In this case a 90-degree bend can be placed on the opening opposite to the suction pipe connection. The bend should be faced upward and the vacuum chamber located above and connected directly to the bend. A water gauge should be connected vertically along the side of the vacuum chamber with a gauge cock at top and bottom. An air ejector will be required at the top of the vacuum chamber to regulate the water level within the chamber.

PUMP DISCHARGE PIPING.—The discharge piping should be of such diameter that the water will not be required to exceed a velocity of 5 to 7 feet per second. It should have as few bends as possible, and be equipped with a gate valve near the pump, and a check valve between the gate valve and the pump.

Direct-acting reciprocating pumps, except in the smaller sizes, should be provided with an air chamber on the discharge side to reduce pulsations. Air chambers should be approximately four to eight times the displacement of the pump. A water-gauge glass should be connected vertically along the side of the chamber with gauge cocks at top and bottom. There should also be a suitable connection to the top of the chamber arranged to release excess air and to supply air. The source of air supply may be an individual air compressor unit or a home-made "snifter," where a suction lift prevails.

The "snifter" is made as follows: A ¾-inch angle valve of the disk or needle type is connected to the top of one of the plunger chambers. A ¾-inch pipe extends vertically from the valve to, or above, the top of the air chamber, and the side opening of a ¾-inch tee is attached to the vertical pipe. In one end of the tee insert a ¾ × ⅛-inch reducer, a short ⅛-inch nipple, and a ⅛-inch check valve that permits air to pass toward the ¾-inch tee. In the other end of the tee insert a ¾ × ⅛-inch reducer, a ⅛-inch nipple, and a ⅛-inch check valve, permitting air to pass from the ¾-inch tee and through this check valve. Finally, arrange the ⅛-inch piping to connect to the top of the air chamber. When the pump is operating, the ¾-inch angle valve can be opened and air will be pumped into the top of the air chamber by the action of the suction (partial vacuum) and discharge (pressure) stroke conditions within the pump plunger chamber.

All pipe connections should line up naturally. Forcing them into place with flange bolts is poor practice, as it may draw the pump out of alignment. All pipe connections should be supported independently of the pump, so undue strains will not be placed on the pump casing. To be sure, the alignment of the pump should be checked again after connecting the piping and, if necessary, the alignment is corrected before operating the pump.

INSTALLATION, OPERATION, AND MAINTENANCE.—Where two or more pumps are to be operated, discharging into the same plant header or distribution mains, special care should be taken that the pumps are designed for the same maximum head conditions. A pump, especially of the centrifugal type, if designed for lower head conditions will "cut-back" or decrease in the quantity discharged per minute, and will "cut-out" or cease to discharge, if the cut-off point (maximum head) of the other pump or pumps, is sufficiently higher. This is also true with direct-acting steam pumps.

Proper location of a pump will facilitate good operation. This matter is frequently neglected at both large and small pumping plants. A light, dry, clean room, where the temperature can be regulated, with sufficient head room and ample space between pumps and nearby walls should be one of the first considerations.

Foundations should be rigid, about 1 inch lower than pump base elevation, with foundation bolts of proper size, and having threads of sufficient length above the foundation. A template should be used to insure proper spacing when foundations are constructed. The pump should first be placed upon the foundation to proper elevation and alignment, with bolts in place. The nuts are then run down on bolts until the threads just project above their tops. Then iron or steel "slow" wedges are placed around between the foundations and the pump base plate, so the pump can be properly leveled without distorting the plate. Grout should be placed on top of the pump foundation and under the pump base plate to fill the space completely, leaving the wedges in place. When the grout has thoroughly set, the nuts of the foundation bolts can be tightened carefully, after which the pump is again checked as to proper elevation and alignment.

The installation of smaller pumps, steam or electric drive, that are furnished with a common base plate for the pump and the driving mechanism, is comparatively simple. The same may be said for the simplex and duplex steam displacement types and the direct-connected electric motor-driven types. In the larger sizes, when water and steam ends are furnished, separately or in sections, the erection should be supervised by a factory representative.

The pump should always be located as close to the source of water supply as conditions will permit. The ideal pump elevation would be at a point sufficiently below the level of the surface of the water so the pump would be primed at all times. In such cases a gate valve should be installed on the suction near the pump.

When starting a large centrifugal pump, see that it is filled with water, the suction valve is open, and the discharge valve closed. When up to speed, open the discharge valve slowly until the desired capacity is obtained. It should be recognized, however, that operating a pump with the discharge partially closed decreases efficiency and wastes power. See that the stuffing box glands are not drawn too tight, and remember that a drip or slight flow of water from the water seal and through the packing in a stuffing box keeps the packing in good condition and indicates that the shaft is not subjected to unnecessary packing friction. Before stopping the pump, close the discharge valve slowly; then stop the pump. This will prevent water hammer on the check valve located in the discharge piping.

In the smaller centrifugal pump installations, especially where automatic starting and stopping equipment is used, the above paragraph does not apply. Some automatic equipment is operated by water pressure from the discharge; electric motor-driven equipment is operated by floats installed in an elevated tank ''floating'' on the discharge system at some distance from the pump. For one pump a two-wire connection and for two pumps a three-wire connection is desirable to operate electric remote control from distant elevated tanks. Pressure switches are also used in automatic control of pumping. They should be installed with an air chamber, throttling valve, and long control lines to minimize rapid pressure fluctuations.

POWER SOURCES.—*Steam.*—The type of power available to drive a pump is a most important consideration. If the pump is to be installed near boilers already in service, so that steam is available, the direct-acting steam pump is of low first cost, reliable, and practically fool proof. The single or duplex types may also be considered. If large capacities are required, then the crank-and-flywheel type, or for still larger capacities, and especially with the low and medium head conditions, the centrifugal or turbine type pump driven by a steam turbine can be considered.

Oil engines.—These include the Diesels and semi-Diesels. They are of constant and comparatively low speed. They are high in first cost but are reliable and economical. They are frequently used in small installations where electricity is not available, high in price, or unreliable. They require considerable operating skill.

Gasoline engines.—These are generally used only as standby or emergency units. They are low in first cost, but very high in operating cost. They generally operate at 1000 to 1600 revolutions per minute with speed control at the carburetor. They should have 25 per cent excess capacity to allow for wear of the valves. They can be direct-connected to centrifugal pumps. A common installation is to have an electric motor on one end of the shaft and the gasoline engine at the other end where it can easily be coupled on should the current or motor fail.

Motors.—Electric motors can be secured in a wide range of speeds, and are well adapted for direct connection to centrifugal pumps and to reciprocating pumps and other slow speed pumps by using such speed reducers as belts, chain, or gear drives. The capacity of a motor depends upon how much heat it can stand, and in sizes under 100 H.P. should be at least 120 per cent of the power required to operate the pump.

The speed of direct-current motors varies directly with the square root of the voltage and the capacity of a centrifugal pump varies greatly with changes in pump speeds. Direct current cannot be economically transmitted great distances. Constant-speed shunt and compound-wound direct current motors are suitable for water pumping. Where pumps are manually operated shunt-wound motors can be used, but where starting power requirements are large, as in automatically controlled installations, the compound-wound motors should be used. Standard adjustable speed motors are available up to a speed range of 5 to 1, and by selecting a pump having the proper characteristics, the proper variation in head and capacity can be obtained by the field speed control. Standard variable speed motors are inefficient when running at less than full-load speed, as they draw as much current at low as at high speeds. This may be overcome, however, by the increased efficiency of the pump unit. This statement does not apply to certain special types of variable speed motors.

Alternating current motors of three types can be secured, each offering three distinct types of service. They are: the squirrel-cage induction motor, the wound-rotor (slip-ring) induction motor, and the synchronous motor.

The squirrel-cage motors do not have moving rings, brushes, or wire connections to the rotating part, the speed is constant, as fixed by the frequency and number of poles. They are without adjustment, and are easily controlled manually or by remote control equipment. The starting torque is low, and when demanded, the current draft on the line is heavy. Their efficiency is high but the power factor is low. They are not well adapted to starting heavy loads, require larger transformers and power lines, and generally higher cost for power used.

The wound-rotor or ''slip-ring'' motor has similar windings on the rotating and stationary parts, with the ends of the windings connected to the ''slip-rings'' on the shafts. The starting torque can be varied from 30 to 375 per cent of full-load torque. These motors are of variable speed, and cost from one and one-half to two times the cost of squirrel cage motors, but the saving in power when the head varies will more than pay the interest and depreciation on the additional investment. The power factor is less than unity, requires larger transformers and power lines, and generally higher cost for power used.

The synchronous motor permits the power factor to be adjusted and is sometimes favored with lower power rates. It is reliable in operation and simple, the speed is constant and the efficiency high. A small generator is necessary to energize the field magnets, but it is generally arranged on the end of the motor shaft.

DRIVE CONSIDERATIONS.—Steam power is used as a drive either direct, as in reciprocating pumps, or by belt, chain, or gears, as in the steam turbine. Electric motors generally operate direct-connected to centrifugal pumps, but belt, chain, or gear drives, are necessary in operating the low-speed reciprocating pumps. Internal combustion engines generally require speed-increasing connections to operate centrifugal types and speed-reduction devices to operate reciprocating pumps.

Belts should not be operated at speeds in excess of 60 to 70 feet per second, and should be operated horizontally. The lower part, from the driven pulley to the driver pulley, should be the "tight" side, the upper part the "slack" side. The thin edge of all splices on the side next to the pulley should point away from the pulley it is approaching. Leather belts should be operated with the hair side of the leather to the pulley; the grain side should not touch the driver or driven pulley. Idler pulleys will reduce slippage of belts and will tend to save space, especially where they are operated at an angle with the horizontal, but they reduce efficiency. The width of the belt depends upon the horsepower to be transmitted, the arc of contact around the pulley, and the speed in feet per second; if made of leather, then whether single, double or three ply; if so-called rubber belting, the number of plies and weight of the duck used in its construction.

Chain drives require less space than belt drives and are suitable for greater power at slow speeds. They have longer life in damp or heated places, and if properly designed make less noise than gears. Under poor operating conditions, however, they may become noisy and inefficient.

Roller chains operate better on horizontal drives. Where the center-to-center distance (drive to driver) is not too short, the "slack" should be below. The maximum speed of the chain is dependent upon the design or type of the sprocket, which in turn is dependent upon the pitch, width and weight per foot of the chain. Silent or high speed chains can be operated in either direction and at speeds of 25 feet per second without noise or shock.

Gear drives are fairly efficient and require very little space. Generally, however, they become noisy, and permit very little flexibility. Most failures are due to faulty design, inaccurate workmanship in installation, lack of lubrication, or foreign matter in the oil which prevents proper lubrication.

WELL PUMPS

RECIPROCATING WELL PUMPS.—Deep-well power pumps of the reciprocating type are generally driven by power applied to the shaft of the power head, which is located at the surface of the ground. The pumping element, cylinder and piston, should be located below the water level in the well. The connecting (drop) pipe and rods, connect the power head with the cylinder, forming a discharge pipe for the water from the cylinder to the surface.

The single-stroke or rod pump is a reciprocating power-driven pump having a single pump rod connecting the mechanism of the pump head with the plunger or piston within the pump cylinder. The plunger may be of the single or double-acting type.

The two-stroke or double-rod type pump is a reciprocating power-driven pump having two pump rods connecting the mechanism of the pump head with the two plungers within the pump cylinder. One set of rods is hollow and of a larger inside diameter, the other solid, and of an outside diameter to work inside the hollow rods. The weight of the hollow rods practically balances the weight of the solid rods, and the two plungers within the cylinders are single acting, working one above the other; one in the upper half, the other in the lower half of the pump cylinder. Connections in the pump head are arranged on opposite throws (180 degrees) of the crank shaft.

The three-stroke or triple-rod type pump is a reciprocating power-driven pump, having three pump rods connecting the mechanism of the pump head with three plungers within the pump cylinder. One set of rods is solid, a second set is hollow and working outside of the solid rods, while the third set is also hollow and working outside of the second. The weight of each set of rods is practically the same, and the three plungers working within the cylinder are each single acting, working one above the other; one in the upper third, the second in the central third, and the other in the lower third of the pump cylinder. Connections in the pump head are arranged on three throws (120 degrees) of the crank shaft.

When calculating the efficiency of deep-well pumps, all of the internal losses up to the discharge connection of the pump head (cylinder, pipe, rods, and mechanism of the power-driven pump head) should be charged to the pump, and the brake horsepower required to drive the unit calculated as follows: Pounds of liquid per minute, multiplied by total head in feet of liquid, then divided by 33,000, is the water horsepower. The water horsepower divided by the horsepower required to drive the pumping unit will give the ratio of output to input or the percentage pump efficiency.

The total head upon which the horsepower of a deep-well pump is based is the vertical distance from the level of the water in the well when the pump is operating, to the center-line of the discharge pipe of the pump-head mechanism at the surface of the ground, plus the discharge head measured at the discharge outlet of the pump-head mechanism. The capacity of a deep well reciprocating power-driven pump is based upon the plunger displacement per minute.

If a reciprocating well pump is to deliver water above the surface of the ground, then a large air chamber should be connected to the discharge pipe between the discharge connection of the pump head mechanism and the check valve in the discharge line. This will be a great aid to the pump rods and will smooth out the pulsations noticeably before reaching the discharge check valve. If pumping against high heads, and especially if two or more such pumps are discharging into the same pipe, additional air chambers on the flow line will relieve the discharge piping of the vibrations caused by the pulsations from the various pumping units.

Most deep-well pump troubles are caused by lack of water. The pump should not be operated at a greater speed than the well will supply water to the cylinder. Single-acting pumps will jar and vibrate when not getting a sufficient supply of water, and a double-acting, two-stroke or three-stoke pump, will discharge water in intermittent gushes. The breaking and rapid wear of rods, the pronounced wear of the working parts of the power-driven pump head, can be attributed to lack of water. If this condition exists the pump should be operated at lower speed or a smaller diameter cylinder installed.

TURBINE WELL PUMPS.—Practically speaking, vertical centrifugal pumps of the small outside diameters that can be used in deep wells are known as deep-well turbine pumps. The pumping element, consisting of a series of impellers, is located under the water within the well; the discharge head is at or above the surface of the ground; and the pipe column connects the pumping element within the well and the discharge head at the surface. The pipe column not only conducts water discharged from the pumping element within the well to the discharge head at the surface of the ground, but also supports the line-shaft bearings if the pump has water-lubricated bearings, or the housing and line-shaft bearings of the oil-lubricated shaft type. The line shafts and housings (of oil-lubricated shafts) are made in standard lengths, the lengths depending on the diameter of units and also upon the depth of the setting.

Wells should be bored straight and truly vertical. In order to prevent damage to the pump, the well should be plumbed before the pump is lowered into the well, and if the deviation is not greater than the clearance necessary for the equipment, then the pump may be lowered into the well; but, if the deviation is greater than the clearance necessary, then the well should be rebored, reamed, or straightened, or a smaller pump with a lower diameter requirement should be used. Forcing pumping and line pipe equipment into crooked wells should not be permitted as serious damage may result. In all probability binding of the shaft in the bearings will occur so that satisfactory operating conditions will be impossible. Dresser or other special types of couplings may be used in discharge piping to give some flexibility and overcome a slight misalignment of the well. Care should be taken that the pump hangs free when in position and ready for foundation or base plate to be grouted in place. Thereafter the foundation bolts may be tightened.

A new type of turbine pump that has the motor submerged in the well is now available. It is claimed that this arrangement avoids the friction and other troubles encountered with a long shaft.

THE AIR LIFT.—Air lift is an apparatus for raising water from wells through a discharge or eduction pipe extending from the surface of the ground downward within the well to the proper depth to secure the greatest efficiency. Compressed air is conducted through an air pipe downward within the well, and discharged into the foot piece at or near the bottom of the eduction pipe so as to mix air with the water in small or large bubbles.

The compressed air enters the discharge pipe near the bottom at a pressure only slightly above hydrostatic pressure; the column of water within the discharge pipe moves upward. The air bubbles continue to expand until the outlet is reached and atmospheric pressure prevails. The mixture of air with the water lessens its specific gravity and since it is lighter than the column of water outside the eduction pipe it moves upward.

The specific considerations of an air-lift installation are as follows: (1) Static head; the normal water level in well when not pumping, measured from the surface of the ground or top of well casing. (2) Drop; the difference between static head and water level in well when pumping. (3) Pumping head; the difference between the elevation of the water in the well when pumping and that of the surface of the ground or top of the well casing. (4) Elevation; the level above the surface of the ground or top of well casing to which water is raised. (5) Lift; the distance water is elevated from level in well when pumping to the point of discharge. (6) Submergence; the distance below the pumping level at which air is admitted to the foot piece at or near the lower end of the discharge pipe. 100 per cent (7); vertical distance air-water mixture travels from point air is introduced to point of discharge. Lift (5) plus submergence (6) equals 100 per cent (7). (8) Starting submergence; the distance below static (1) at which air is admitted to shoe and includes drop (2) plus submergence (6).

The static head (1) plus the drop (2) equals the lift (5), when discharging at the surface of the ground.

The elevation (4) plus the static head (1) plus the drop (2) equals the lift (5), when discharging above the surface of the ground.

Submergence practically governs the starting and working air pressures required; the maximum efficiency is secured when the submergence is approximately 2.25 times the lift, although this ratio becomes less for low lifts and higher for high lifts. The rela-

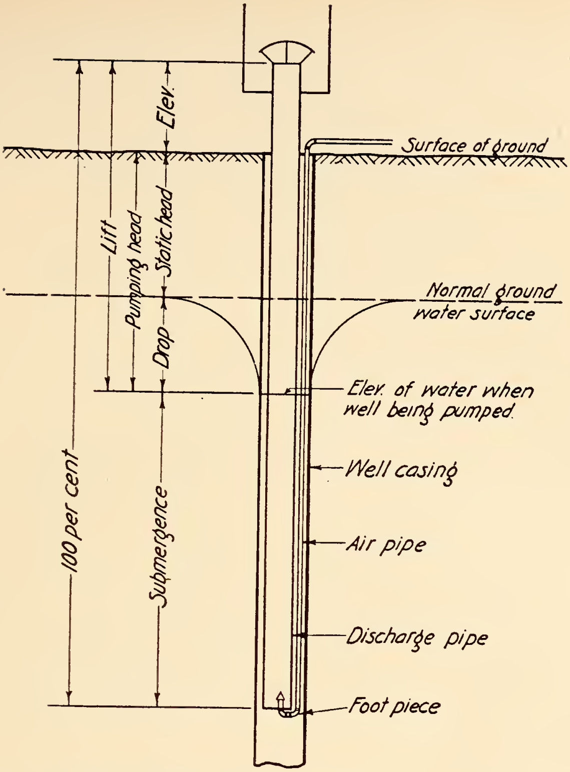
Elev.
Surface of ground
Lift
Pumping head
Static head
Normal ground water surface
Drop
Elev. of water when well being pumped
100 per cent
Submergence
Well casing
Air pipe
Discharge pipe
Foot piece

FIG. 12. Diagram illustrating air-lift pumping of wells.

tion between submergence and lift may also be expressed as some per cent of the 100 per cent (7). This per cent varies from 40 for lifts of 400 feet to about 65 per cent for a lift of 50 feet.

The principal loss of efficiency seems to be due to slipping back of water caused by friction in the discharge pipe. Use of air lift should be limited to cases where efficiency can be sacrificed for a reduction in maintenance expense, to obtain an increase in well output or an increase in reliability. It is also applicable to crooked wells, wells of small diameter, where the water contains much sand, and where the water must be raised from a depth of 200 feet or more. It should discharge to vertical piping only, as in horizontal or even inclined piping the air in the air-water mixture separates or tends to pass along the upper side of pipe, thus permitting water in the lower part to lag or decrease in velocity, or even slip back.

CHAPTER VI

MEASUREMENT OF WATER

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The problem of measuring the flow of water is continually confronting the water works man. It is a problem that must be solved under widely varying conditions. The purpose of this chapter is to discuss various methods of measuring water flow and to indicate the conditions to which they are applicable. Measurement of water passing through consumers' services, however, will be found in Chapter VIII.

WEIRS.—A weir is a barrier over which water flows, or a notch in such a barrier through which the water flows. If sufficient information is known concerning the weir it is a simple procedure to compute the amount of water flowing over it or through it. Since a weir can be easily set up this means of water measurement is applicable to checking the flow of a well or to ascertain the flow from a spring.

The *crest* is the point or level of the weir to which water must rise before there is any overflow. The *head* on the weir is the vertical distance from the crest to the water level in the pool immediately upstream from the weir. The most commonly used weir is the rectangular type having a sharp crest. The length of the weir in this case is the length of the crest. See Fig. 13.

The flow over a sharp-crested weir can be found by the Francis formula, which is

$$Q = 3.33LH^{3/2},$$

in which Q is the flow in cubic feet per second, L is the length of the weir in feet, and H is the head in feet.

For the Francis formula to be applicable the following conditions must be satisfied: The crest must be sharp and level. The sides must be vertical and parallel. The channel of approach to the weir should be deep enough so that there is not a swift current in the pool above the weir. The head should be measured far enough above the weir to avoid the effect of the surface curve, or a distance of at least 3 times the head on the weir. The stream of water must flow freely over the weir so that air may circulate beneath it.

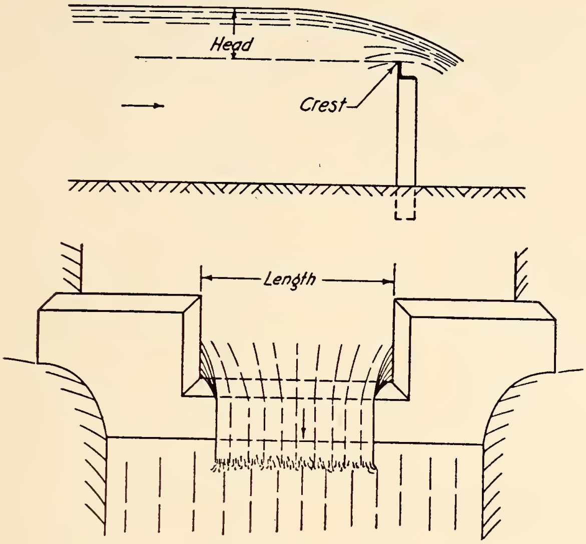

FIG. 13. Section and view of rectangular sharp-crested weir.

As the water flows through the ordinary weir there is a contraction of the stream at the sides which reduces the flow. This is cared for by reducing the weir length, L in the formula, by 0.1 H for each end contraction. End contractions may be eliminated by constructing a weir box with its sides forming the approach channel and ending flush with the sides of the weir.

Table V gives the quantity of water discharged per foot length of a rectangular sharp-crested weir. If there are end contractions the actual length of the weir must be reduced by the appropriate amount. For example: A sharp-crested weir 1 foot long has two end contractions. The head on the weir is 0.5 foot. Determine the discharge. The discharge with this head for a weir 1 foot long by Table V is 530 gallons per minute. The end correction will be $2 \times 0.1 \times 0.5 = 0.1$ foot. The working length of the weir therefore is only 0.9 foot, and the corrected discharge is $0.9 \times 530 = 477$ gallons per minute.

TABLE V.—DISCHARGE OF A SHARP-CRESTED WEIR PER FOOT OF LENGTH BY THE FRANCIS FORMULA *

Head Expressed in		Discharge Gallons per minute	Head Expressed in		Discharge Gallons per minute
Feet	Inches		Feet	Inches	
0.01	⅛	1.5	0.32	3⅞	271
0.02	¼	4.2	0.34	4⅛	296
0.03	⅜	7.8	0.36	4⅜	323
0.04	½	11.9	0.38	4½	350
0.05	⅝	16.7	0.40	4¾	378
0.06	¾	22.0	0.42	5	407
0.07	⅞	27.7	0.44	5¼	436
0.08	1	33.8	0.46	5½	467
0.09	1⅛	40.4	0.48	5¾	497
0.10	1¼	47.2	0.50	6	530
0.12	1½	62	0.55	6⅝	610
0.14	1⅝	78	0.60	7¼	690
0.16	1⅞	96	0.65	7¾	780
0.18	2⅛	114	0.70	8⅜	870
0.20	2⅜	134	0.75	9	970
0.22	2⅝	155	0.80	9⅝	1070
0.24	2⅞	176	0.85	10¼	1170
0.26	3⅛	198	0.90	10¾	1270
0.28	3⅜	222	0.95	11⅜	1380
0.30	3⅝	246	1.00	12	1500

* From "Water Works and Sewerage Data, 1936." Published by Gillette Publishing Company, Chicago, Ill.

THE VENTURI METER.—The principle of the Venturi meter, which was first discussed by the Italian engineer of that name, is widely used in water works practice. Meters of this type can be used to measure the rate of flow of fluids, both gases and liquids, and they are well adapted for large flows. Hence they are installed in pumping plants to measure the total output or the output of individual pumps. The rate controllers of sand filters are in effect Venturi meters, with the pressure difference operating a throttling valve that keeps the flow constant. Wash water application rates may also be controlled by the Venturi meter. The principle has also been employed to apply chemicals that are automatically dosed according to the rate of water flow.

The Venturi meter is illustrated by the diagram shown in Fig. 14. It consists of a throat or constricted section placed in the pipe, with devices to measure the pressure at the throat and just ahead of it. For simplicity they are here shown as open tubes. The action of the Venturi meter is based upon the fact that when the velocity of water is increased there is a decrease in its pressure and for any particular Venturi tube the pressure decrease is proportional to the square of the velocity at the constricted section.

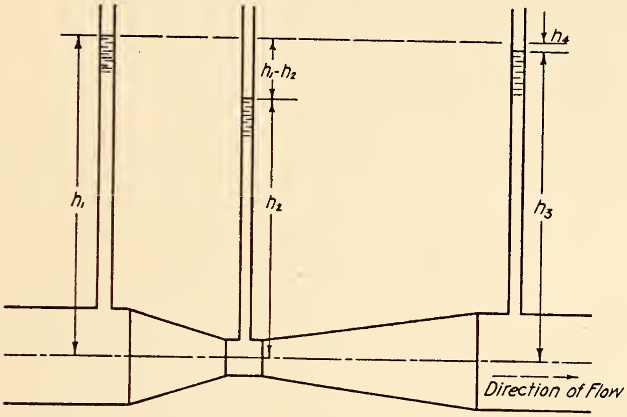

FIG. 14. Diagram of the Venturi meter.

An analysis of the theory of the Venturi tube depends upon recognition of the conservation of energy. As applied to running water the total of pressure energy and velocity energy at an upstream point is equal to the sum of the pressure energy and velocity energy at the downstream point plus the energy lost in overcoming friction between the two points. Pressure energy can be expressed in feet head of water as shown by a gauge or tube, while velocity energy can be translated into feet head of water by the equation

$$h = \frac{v^2}{64.4},$$

in which h is the velocity head in feet of water and v is the velocity in feet per second at the point where the value of the head is desired.

Applying this to Fig. 14 the total of energies at the upstream pressure tube will be equal to the total of energies at the throat. Expressing this as an equation, and neglecting the frictional loss for the moment, it will be

$$h_1 + \frac{v_1^2}{64.4} = h_2 + \frac{v_2^2}{64.4} \tag{1}$$

and

$$h_1 - h_2 = \frac{v_2^2}{64.4} - \frac{v_1^2}{64.4}\,. \tag{2}$$

Since the diameters of the pipe and constricted section are known and the amount of water flowing past each section is also known it is possible to express the velocities in terms of the quantity flowing and the diameters of the pipe.

$$Q = a_1v_1 = a_2v_2 \qquad \text{or} \qquad v_1 = v_2\frac{a_2}{a_1} = v_2\frac{(d_2)^2}{(d_1)^2},$$

in which Q is the quantity flowing and a_1 and a_2 are the areas, and d_1 and d_2 are the diameters in feet at the two points. Substituting this value of v_1 in equation (2) and solving for v_2 we have

$$v_2 = \sqrt{\frac{64.4(h_1 - h_2)}{1 - (d_2/d_1)^4}}\,, \tag{3}$$

in which v_2 is in feet per second, h_1 and h_2 are in feet, and d_1 and d_2 are in feet.

The v_2 of equation (3), however, is only a theoretical value since there is some small loss of energy caused by friction. Consequently the actual v_2 will have an average value of about 0.98 of the theoretical. The 0.98 is known as the coefficient of velocity. By combining all of the constants of equation (3) and the coefficient of velocity into one constant K the relationship can be written

$$v_2 = K\sqrt{h_1 - h_2}. \tag{4}$$

With the area of the throat at point 2 known the quantity flowing can be computed. In Fig. 14 the head h_4 is the loss of energy in the water incurred in passing through the Venturi tube and pipe from point 2 to point 3.

Venturi meters are manufactured by a number of firms. They include various devices for showing the differential in head and in the scales or dials furnished the differential may be expressed directly in terms of actual flow. Recording devices are also obtainable that give a permanent record of fluctuating rates of flow. If the meter is to register accurately it should be installed with straight pipe preceding it for a length equal to 6 times the diameter of the throat for the smaller meters and at least 12 feet for meters over 24 inches in size.

THE ORIFICE METER.—Velocity of flow in a pipe can also be measured by observing the drop in pressure as the water passes through a circular orifice in a diaphragm. Fig. 15 shows such an arrangement. The orifices are in thin non-corrodible metal and are accurately machined and beveled as shown, with the center of the orifice coinciding with the center of the pipe. The diameter of the orifice should not exceed 80 per cent of the pipe diameter and the pressure gauges should be located as shown.

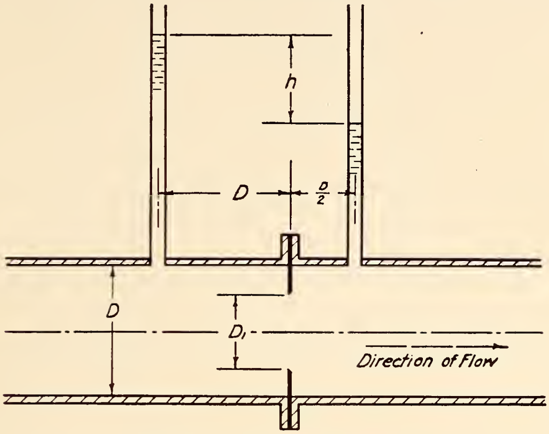

FIG. 15. The orifice meter.

By reasoning similar to that applied to the Venturi meter it is possible to derive the formula for the orifice meter. It is

$$v = C\sqrt{\frac{64.4h}{1 - (d_2/d_1)^4}},$$

in which v is the velocity through the orifice, h is the difference in head shown by the two gauges, d_2 is the diameter in feet of the orifice, d_1 is the diameter in feet of the pipe, and C is a coefficient having the value of about 0.606 for values of d_2/d_1 ranging from 0.10 to 0.75.

The orifice meter is easily installed and sufficiently accurate for measuring flows at pumping plants. It can be purchased from manufacturers with indicating and recording devices that show flow and flow variations on gauges or charts.

THE PITOT TUBE.—Fig. 16 is a diagram showing the principle of the pitot tube. It consists of a tube projecting into the pipe, with a 90-degree elbow on its lower end and with the opening directed toward the current. In order to ascertain the velocity of flow an ordinary flush pressure tube must also be used close to the point where the pitot tube is inserted. The flush tube indicates the pressure head of the water. The current striking the open end of the elbow tube encounters a condition which transforms the velocity energy of the water into pressure energy and this transformed energy is indicated by the greater height h to which the water rises in the pitot tube. The velocity at the point where the elbow is located can be computed by the equation

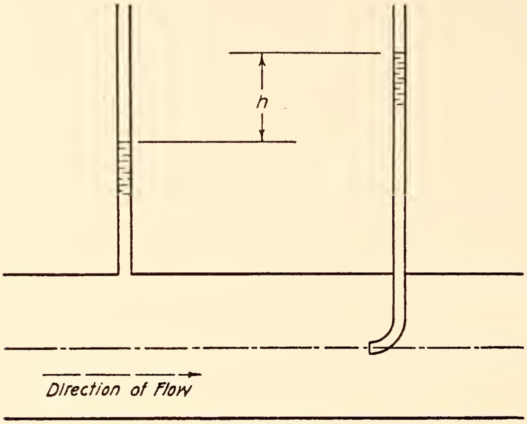

FIG. 16. The pitot tube.

$$v = \sqrt{64.4h},$$

in which v is the velocity in feet per second and h is the difference in the pressure heads of the plain tube and the pitot tube.

If the tube is preceded by straight pipe for a length of at least 50 pipe diameters the average velocity in the pipe can be computed by multiplying the velocity found at the center of the pipe by 0.83. If there is an elbow or other disturbing condition within 50 pipe diameters of the tube a number of readings should be taken systematically across the pipe diameter and averaged.

Commercial pitot tubes, sometimes known as pitometers, can be purchased. They are designed for easy insertion into the pipe.

Usually they consist of two tubes variously arranged with provision for reading the pressure-head difference. These types require use of a coefficient with the pitot tube formula and the coefficients are given by the manufacturers. The pitometer may be used to measure flow at a pumping plant and it is also used in leakage surveys throughout the distribution system (see Chapter VIII).

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Chapter VII

STORAGE RESERVOIRS

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Storage reservoirs of one kind or another are very necessary in the design and operation of a community water supply. The type, or types, to be used, and the particular way in which they are utilized to best advantage in a given water supply system, depend upon local conditions. The maximum variation of the ground elevations in the area served, the distribution of the system load, and the desired operating main pressures are the principal factors which govern the choice of type and the function of the reservoir used. In the larger water works systems it often happens that a combination of two or more reservoirs, with a different function for each one, proves to be the best plan.

The fundamental purpose of reservoir storage may be summed up as a device to permit maximum economy and quality of service in the production and distribution of the water supply of a community. This goal is arrived at through three primary results—reduced investment costs, reduced power costs, and continuity of service under satisfactory pressures.

Types of Reservoirs.—There are two general types of reservoirs. One type is built at or slightly below the ground level. Its influence upon pressure in the water distribution system depends upon the elevation of the ground surface, and the height of water in the reservoir. This type is constructed along two general designs. One has a low height in relation to the area covered. Such a design is used where the natural ground elevation on which it is located gives the necessary minimum pressure in the distribution system which the unit serves. The other design is built with a height several times the horizontal dimensions. This may be adopted because of the need for additional elevation to obtain sufficient pressure, or to secure the required storage capacity where the ground area available is limited.

Site considerations result in use of the second general type of reservoir. It frequently happens that none of the available sites are high enough to serve the desired purpose. The minimum water pressure necessary in the system to be served from the given unit requires that the water level in the reservoir reach a definite height. If a structure is built at the ground level for this condition, as the standpipe, the storage capacity created would be excessive unless relatively small dimensions are used for the horizontal section. In that case the full storage capacity would not be available except with subnormal operating pressures as the water level dropped. The need for higher elevations of the water level, coupled with definite storage capacity requirements, has developed the elevated storage tank. It is probably the most generally used type. The designer may determine independently the three factors of best available location, volume of storage most suited to the needs, and the proper elevation at which the water should be stored. These given needs can be met readily by an elevated tank of the given capacity placed on a tower of sufficient height to furnish the desired pressure. The entire unit is, of course, designed to be structurally sound and as attractive in appearance as possible. This result is usually accomplished by securing bids from reputable firms specializing in elevated tanks. They will submit bids for a given structure completely installed to comply with given elevation and storage requirements at the designated location. Choice of a tank may then be made through a study of drawings, cuts, and descriptions of the units submitted, properly influenced by the cost figures and reputations of the manufacturers and sales representatives.

STORAGE FOR WELL SUPPLIES.—The simplest use for water storage is in connection with a well supply. Usually the water is pumped from the wells into a surface tank. Such a tank may also be of advantage by acting as a sand trap. Unless it is to be treated before using, the water is taken from this tank by the system supply pumps. In addition to forming a necessary stage in the supply operation from wells to mains, this reservoir is usually built of sufficient size to provide a reserve supply against possible shut down of the well pumps for any reason. This arrangement also enables the operator to pump from the wells at a fairly uniform rate that is best suited to their capacity. The life of the wells is thereby prolonged. Excessive pumping of a well to meet peak demands will often destroy an otherwise permanent source of water supply. Such reservoirs will also make up, in considerable degree, in small cities for deficiencies in wells and well pump capacities and thereby reduce insurance rates.

ADVANTAGES OF DISTRIBUTION STORAGE.—The use of ample storage capacity in a water distribution system is highly economical. Without elevated storage the necessary size of a pumping plant is determined by the maximum rate at which it must supply water to the system. By the use of elevated storage located on the high point of the area served it is possible to maintain adequate and dependable service with a much smaller pumping plant. With a full reservoir connected to the system it can be depended upon to furnish a large part of any peak demand, when it occurs, by automatically feeding into the mains a part of the previously stored surplus. At night, while the rate of actual demand on the pumping plant is low, this surplus can be systematically built up by the pumps operating under the most efficient load. Such a reservoir is said to be "floating on the line."

By thus equalizing the load on the pumping plant the cost of power is materially reduced. Operation of the pumps under more uniform and normal loads gives greater efficiency and lower power costs. This saving is especially large when use of a stored reserve avoids daily starting up of an extra pump for the short peak-load period. In many cases where purchased electric power is used, elimination of an extra motor for the short period means a big decrease in the demand charge item on the power bill.

Particularly in small cities, or in restricted sections of large cities, ample elevated storage will permit automatic operation of pumps. Float-controlled switches can be arranged to start motors when the tank level is low and cut off when the tank is filled. This arrangement reduces labor cost, usually power cost also, and assures more uniform pressures and reliable service. In general, control with float or pressure switches is desirable to keep both surface and elevated tanks full and thereby to insure against depletion of the stored water at some time when it is badly needed.

One of the most important functions of a storage reservoir is to insure fire protection and adequate domestic supply during a shut down of the pumping plant. This applies with equal force for a break in a feeder main for the entire supply, or for a particular section of the city. Fire insurance rates have a very definite relation to the reliability of a water supply for fire protection purposes. In Texas the State Fire Insurance Commission has established minimum requirements for the water supply of a community and these must be met to secure full credit on the fire insurance key rate. The minimum available water supply under the operating pressure must be 110 gallons per capita per day. A storage capacity of not less than 50,000 gallons must be available for the system pumps to draw upon. In addition there shall be a like amount at a minimum elevation of 100 feet above the water system served thereby. This requirement can be fulfilled either by an elevated tank or a ground-level structure on high ground, where such is economically available. Savings in fire insurance premiums from lower rates obtained by reliability of water supply will show a material and very tangible return on the investment in storage capacity.

It frequently happens that one section of a city is supplied through a long feeder main that is of inadequate capacity during peak demands. To supply the additional capacity needed, the operating pressure at the pumping plant may be raised. This plan, however, is limited by several factors, including the following: (*a*) Safe operating pressure of pipe used in mains. (*b*) Increased pressure causes material leakage losses. (*c*) Pump efficiencies at the plant may be reduced. (*d*) Extreme pressure variations near the plant may cause objectionable conditions for consumers.

Such a problem is best solved by a suitable storage tank connected to the distribution system in the proximity of the given area. While acting to equalize the load on the feeder line to the given area, the reservoir will stabilize the supply pressure and prevent undue pressure fluctuations. It will fill up while demand on the water supply is low. When increased consumption of water tends to lower the feeder supply pressure the stored supply will feed back into the mains and maintain the pressure within a reasonable variation. Of course this reservoir operates to secure the other advantages of storage for the area involved. Particularly does it furnish insurance against interruption of supply through the feeder main in case of a break in the line, or of a plant shut down. Also were it not for this reserve supply additional mains and feeder lines might be needed.

It is to be noted that usually any given reservoir serves in several of the various capacities enumerated, though, as a rule, one particular need or problem is the primary purpose behind its installation. When one is to be installed, the various factors involved must be carefully studied by a competent engineer. Each influence contributed by the proposed structure should be weighed in order to secure the maximum value for each dollar invested in the contemplated reservoir.

SURGE TANKS.—A special type of reservoir is the surge tank. Its purpose is to absorb pulsations and pressure increases which may develop in a long pipe line. If the line is of gravity type running, perhaps, from a reservoir to a city, the surge tank will be placed near the outlet end. If the line is fed by pumps the surge tank will probably be placed near the pumps. Such tanks are small in capacity.

AUXILIARY STORAGE TANKS.—Elevated tank storage is used frequently as an auxiliary in water plant operation. The two principal reasons for such use are to eliminate added peak demands on the pumping equipment, and to secure a more certain control of the pressure at which the water is furnished. The best example of this use is an elevated tank to furnish wash water for rapid-sand filter beds. The tank is designed with a low ratio of depth to diameter. This reduces the pressure variation to a minimum as the tank level falls when water is drawn out in washing a filter unit. The water needed for this purpose is raised to the elevated tank between washings, at a low demand rate, from the pumping plant. Since a uniform flow of water in large volume is essential to proper filter bed washing, such an elevated tank furnishes the best source of supply pressure for the purpose.

Some large cities having a gravity water supply from a distant source have found it practical and expedient to provide needed storage capacity through additional large-size trunk supply mains. Where there is no ground in or near the city high enough to meet the pressure requirements of the system for storage, a real problem exists. It may prove impracticable or too expensive to construct distribution reservoirs of sufficient capacity at the necessary elevation. But even in such cases the continuity of supply should not be dependent upon the continuous functioning of a single pipe line. A duplicate trunk main from the primary supply source is essential. Where the capacity of the original feeder line is strictly limited, for any reason, it is practicable to operate the new line under pressure to function as a storage reservoir. The new feeder main may be connected to the original feeder line, and to the several pressure levels of the distribution system through automatically controlled pressure valves located at strategic points. During the periods of peak demand this new line will act very similar to elevated storage. As the pressure tends to fall from increased demand in any part of the distribution system, the additional supply of water required will be automatically furnished, thereby maintaining the pressures within reasonable limits to fit the system design.

STRUCTURAL CONSIDERATIONS.—Storage reservoirs are constructed of reinforced concrete, steel, or, in some instances, of brick or of wood. The choice of material is governed largely by the circumstances. Other things being equal, reinforced concrete is the preferred material. It does not deteriorate in contact with water, and requires very little maintenance. There is also freedom from iron rust or scale in the water supply incident to corrosion of the inside surface of steel tanks.

One primary controlling factor in design, including choice of the material used, is the need for structural safety and stability. this is usually the consideration which determines the choice of material used. For most ground-level installations concrete may be used. When the conditions call for a ground-level tank of the standpipe variety, the increased height necessary will probably make a concrete structure unwieldy and more expensive than steel. Should the situation call for an elevated reservoir, steel construction becomes economical and practical. The savings in first cost, in any case, should be sufficient to justify the increased expense of maintenance on the steel against deterioration. In some cases the steel design is dictated by the need for staying within an available amount of funds for the first cost.

In designing reservoir storage for a community, the aesthetic angle should be given whatever value the inhabitants desire and are willing to pay for. There may be instances in which an elevated storage tank structure can be combined with a memorial project, or other civic building. In such cases the influence of the cost factor may become secondary in so far as the water supply angle is concerned. Adequate funds would then be available to design an elevated concrete reservoir with the desired architectural treatment to remove every possible objectionable feature of the unit.

It is essential that the reservoir be strictly water tight. The water supply must be conserved, and leakage of the tank contents would be poor economy. In the case of elevated storage such leakage would be a source of nuisance and complaint. It would also give a poor impression of the operation of the water supply system to the public. A leaking joint or opening in any tank is also a potential source of progressive deterioration not in keeping with efficient management. The public may reason that such carelessness is indicative of unconcern for the quality of the water supply itself.

THE SITE OF A DISTRIBUTION RESERVOIR.—The selection of the site will usually be governed by three factors: (*a*) Highest ground levels available within or adjacent to the area to be served. (*b*) Relative cost of securing and reaching the various sites available. (*c*) Aesthetic consciousness of the people living in contiguous areas.

In small cities it is common to place the elevated tank on the opposite side of the high-value and high-use district from the pumping plant. At periods of high fire-fighting demand or other peak use water will be fed to the district from both sides, thereby upholding pressures in spite of high use. In any case the highest ground level possible is desirable because it reduces the necessary height of the structure. The cost of the unit is thereby reduced in proportion. If, however, the highest available site costs more than the next highest, or requires a more expensive unit to meet the other factors involved, it may prove best to change the location. In the cost factors should be included necessary connecting mains to the sites considered.

NECESSARY CAPACITY.—To insure proper return on the money invested, a given reservoir must be built with ample capacity for the function expected of it. An excessive capacity would tend, through increase in the first cost, to nullify the economic benefits to be derived from the unit. The designer must carefully estimate or otherwise determine the volume of water needed in storage at the particular location selected.

In determining the capacity to be used it is first necessary to decide several items, as follows:

(*a*) Minimum reserve required to meet standby and/or feeder line breakdown needs. This figure very often is fixed by the minimum standards of the fire insurance regulations. The latter figure should only be taken as the minimum, and should not be relied upon to take the place of a careful study of the other controlling factors.

(*b*) Probable growth and development of the area involved during the estimated useful structural life of the materials used in construction of the reservoir.

(*c*) Practicability of raising the volume of water contemplated to the height fixed by the pressure requirements under existing conditions.

SAFEGUARDS AGAINST CONTAMINATION.—With the ground-level type reservoir, particularly if it is partly or wholly underground, the question of contamination of the water supply by means of leaks becomes important. Exclusion of ground water is essential to eliminate possible seepage inward of impure water when the reservoir is empty, or nearly so. In this connection particular attention must be given to design of reinforced concrete structures. Great care is essential to insure freedom from cracking in the bottom slab, and walls where they are underground. Ample steel reinforcing, high grade concrete and good workmanship are vital for this purpose. The construction joints should be designed to remain water tight as well as to provide for the expansion and contraction of the material.

Since the stored water must be kept free from any contamination, the design should include safeguards against the possible sources of pollution or contamination. The reservoir must be covered with a roof of water- and dust-proof material. Every opening into the storage space should be covered by permanent or regularly maintained safeguards. In this connection the number of such openings should be held to the minimum number absolutely necessary for using and maintaining the reservoir.

Suitable vents must of course be provided above the water level to allow rise and fall of the water level in the tank without formation of pressure or vacuum. The vents should have the intake opening looking downward to eliminate dust that tends to settle out of the air. To keep out birds, insects and other vermin, the openings should be covered by copper mesh screen cloth having not less than 18 meshes to the inch.

The necessary manhole openings into a reservoir should likewise be dust and insect proof. Those below the water level of necessity must be completely sealed. Where the openings are above the water level, especially on a horizontal, or nearly horizontal, surface, the danger of contamination must be especially guarded against. At any manhole location the outside surface of the tank should be slightly higher than the surrounding part of the tank, This will prevent possibility of rain water or other moisture from collecting around the manhole ring, where it might drain into the reservoir. It is especially important that the ring project above the surface a few inches. The manhole cover itself should have its edges turned down outside the ring. Provision should be made for locking the cover in place against both accidental and intentional removal, except for legitimate purposes. This is especially important on ground-level reservoirs easily accessible to the public.

Frequently it is necessary to have one or more drain-pipe connections for cleaning or other purposes. Such connections ought to be held to the minimum number. Where they are installed special care is essential to see that they are not connected to a sewer line of any description. The outlets of the drains must be above the highest possible water level in the pipes or basins into which they empty. The drain pipes must also have a continuous fall away from the reservoir. No traps or siphons should be tolerated if safety from contamination is desired.

It is important that no sinks or low places exist at any point around the site of the tank. The top should drain any surface water falling on it to the sides and the earth around ground-level structures should slope away in all directions. This will prevent accumulation of surface moisture against the walls, whence it may seep through to the water within. Another highly important precaution should be taken in connection with tanks partly or wholly below natural ground level. The design of the reservoir should include an efficient system of sub-surface drainage to keep the ground-water level permanently below the bottom of the structure.

MAINTENANCE.—Once a storage structure is built and in service, the question of maintenance arises immediately. Frequent checks of the safeguards against contamination are necessary. This can be done by the operator in charge of the water supply plant. Whenever the interior of a reservoir is emptied and entered for inspection, cleaning, painting or any other purpose, it should be disinfected by some recognized method before being placed back in service.

The reservoirs should be inspected frequently and regularly to see that the vents are screened effectively. When the screens are found broken, they should be repaired at once. Any signs of a surface leak which develops about the storage tanks should be checked as a potential source of danger to the water supply. Manhole covers should be checked to see that they have not been left open or disturbed by irresponsible parties. This is especially important on ground-level reservoirs to which the public has a ready access.

The ground surface surrounding a reservoir of any type ought to be kept graded and shaped, not only to minimize danger of pollution but also because of the definite psychological effect which a good appearance of water works grounds has upon both the public and those in charge of the water system. It makes friends for the management and encourages more pride in keeping the system in first class condition generally. This helps materially when the question of financing new improvements is up for vote of the citizens. Good drainage of the ground surface also protects the foundations of elevated tanks.

Storage structures need periodical cleaning of the interior. The frequency of the need depends upon the characteristics of the water and method of treatment. The material used in construction of the reservoir also has considerable bearing upon the problem. The walls and floor of a concrete or masonry reservoir may become coated with slime. Unless this is removed it may eventually become thick enough to slough off and get into the distribution system. Bad tastes and odors may be introduced into the water supply from this source. The remedy is to empty the reservoir regularly and clean the inner surfaces thoroughly. A thorough scrubbing with a copper sulfate solution, followed by flushing with a hose, will effectively clean the surfaces and wash the removed material out through the drains.

Any structure is subject to deterioration and requires maintenance. The nature of the maintenance required depends largely upon the materials used in construction. Reinforced concrete requires a minimum of maintenance, if of good quality and design. The principal requirement is to see that any cracks which develop are given attention by some one experienced in such repairs. Attention to the proper functioning of the sub-surface drainage system, previously discussed under the subject of design, is one of the best methods of maintenance for this type of structure. If any decorative plastering has been done on exposed surfaces of the structure, it is essential that the finish be kept in good repair. Otherwise the aesthetic purpose of the design will be nullified.

In steel reservoirs the chief need is to guard against rust and corrosion. To prevent this it is necessary that the external surfaces of the tank and supports be first cleaned and then painted with a high grade metal paint. The relation of the tank to the surrounding improvements will frequently determine the most suitable paint colors to use. In recent years the use of aluminum paint for this purpose has become prevalent. It combines durability with an impression of cleanliness due to the silvery appearance. It also has the advantage that the bright surface radiates heat and thereby helps to keep the contents protected materially from heating by the sun's rays. Whatever paint is selected, it should be a product of a firm with an established reputation and which stands behind the material it sells.

On the interior of a steel reservoir the surface should be preserved from effects of the water by a protective coating. The coating must not be a source of poison or bad taste to the water supply. Due to oxygen and other active constituents of stored water, the interior surface of the tank gradually loses its protective paint film and becomes tuberculated and coated with rust. If this condition is neglected, the accompanying corrosion will eat through the walls and injure the tank. Eventually a structural weakness develops to destroy the usefulness of the unit, and necessitates a major expenditure to correct the trouble.

When the regular inspections disclose the need for interior cleaning and painting, the tank should be emptied and allowed to dry inside. The entire surface of the metal should then be cleaned to a bright finish. Special care should be exercised where the surface is pitted, and around rivet heads, or where the metal laps, to clean out the rust and scale in the depressions or angles formed. Otherwise some rust may be painted over, to scale off soon and expose unprotected metal. Scraping, sand blasting and wire brushing are used to clean the metal surfaces. While cleaning the surfaces a close inspection should be made for signs of loose or defective rivets, or construction joints injured by corrosion. Where found, any such places should be adequately repaired by experienced craftsmen before the painting is done.

There are a number of good paints for coating the interior surfaces of steel water tanks. Red lead paint is still the most popular, but recent developments indicate that chromate primers have a definite place in water tank painting, and with many waters are superior to red lead and oil as a protective coating on the inside of steel tanks. The painting should be done by experienced men and strictly according to the specifications furnished by the manufacturer. At least two coats are necessary. Special pains are required to see that a thin uniform coating is applied to every inch of the surface. The first coat must be thoroughly dry and hard before the next is applied. The same holds true about the last coating before the tank is again filled with water.

With the usual type of water supplies, the interior of a metal reservoir should go from 4 to 5 years before needing a new protective coating. If the water is somewhat corrosive this period will be correspondingly reduced. On the original erection, the interior painting should be carefully and expertly done. After the first 2 years an inspection is advisable at least once every 6 to 9 months. If the inspection indicates signs of scale or rust of any consequence, it is time to start plans for the job of cleaning and painting. The old saying regarding an ounce of prevention applies most aptly to the steel water storage reservoir.

Chapter VIII

THE DISTRIBUTION SYSTEM

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The distribution system has its origin at the point from which it receives the water from the supply system. It includes the network of distribution mains, fire hydrants, valves, service lines, meters, booster stations, storage reservoirs, and separate mains laid for fire protection only. Water systems vary in size and efficiency from the town pump and bucket to the modern efficient systems with their high speed pumps, adequate pipe systems, metered services, and fire service. The distribution system has two very definite functions to perform: (1) delivery of an ample amount of water to every type of customer when and as needed; (2) delivery of water in sufficient quantities at any point of the system for adequate fire protection.

Water systems fall in two general classes—privately owned and publicly owned, although occasionally there are combinations of the two. Regardless of ownership, the same general principles apply.

Kinds of Pipe Used.—The vast importance of water supply in civilized life has led to the development of many types of pipes to meet all possible conditions. Accordingly the water works engineer now has cast iron, steel, wrought iron, reinforced concrete, cast iron lined with cement, asbestos combined with Portland cement, and wood staves as materials from which to choose for mains. For the small service pipes he may exercise choice between black and galvanized iron and steel, cast iron, copper, brass, and lead. The use of cast-iron pipe for water mains dates back approximately 250 years, steel pipe, approximately 55 years, reinforced concrete pipe, approximately 45 years, and wood-stave pipe, approximately 50 years, although mains of bored logs were used 150 years ago. Cast-iron pipe is so long lived that it is difficult to say how long it will last. For estimating purposes it is frequently assumed as having a 75-year life. Reinforced concrete may be assumed at 50 years. Steel may last as long as 50 years but under unfavorable conditions may begin to fail after 10 to 15 years. Asbestos (Transite) is of very recent development but its life should be long. It has been used successfully in Italy for the past 20 years. Wood-stave pipe is also variable in length of life, from 10 to 30 years probably being the range. Service pipe materials are discussed later in the chapter.

The carrying capacity of cement-lined pipe is usually greater than that of cast-iron or steel pipes even when the reduction in diameter is considered. Asbestos pipe (Transite) is also smoother than metal and has a greater carrying capacity. The carrying capacity of the metal pipes becomes more or less impaired with age, due to the formation of tubercles and rust on the inside. This condition of the internal wall of pipe is known as corrosion and it sets up an amount of resistance to the flow of water which depends upon the extent of such corrosion and tuberculation. Some waters are very active in corroding pipe and where such water must be conveyed a type of pipe should be selected that is especially resistant to corrosion. Conversely, water may be treated to reduce its corrosive properties to where it will be safe to use in a particular type of pipe. Corrosion-resistant pipes are cement-lined, concrete, wood-stave and Transite.

Carrying capacity, durability, cost, and ability of purchaser to finance, are factors to be considered when making selection of the type of pipe to be used. It is more important to consider the cost of gallons per minute delivered than the first cost of the pipe. This requires calculation of the annual maintenance and overhead costs. The last-named are, of course, especially dependent upon length of life. Each case requires separate comparative estimates and sometimes competitive bids to determine the best value.

SPECIFICATIONS FOR WATER-MAIN MATERIALS.—The American Water Works Association's specifications for cast-iron pipe and fittings are considered as standard. During recent years, and with the advent of centrifugally cast pipe, it has been necessary to seek additional specifications. The Federal Standard Stock Catalogue gives us WWP421 Federal specifications for centrifugally cast bell-and-spigot cast-iron pipe; and WWP423 for bolted-joint cast-iron pipe. Until such time as the American Water Works Association approves a set of specifications for centrifugally cast pipe, the use of Federal specifications is recommended.

Tentative specifications covering cement-lined pipe are obtainable from the Cast Iron Pipe Research Association of Chicago. There are no standard specifications for Transite pipe, which is the product of a single manufacturer, but it is approved for water mains by the National Board of Fire Underwriters.

AMOUNT OF WATER TO BE CARRIED BY THE WATER MAINS.—A distribution system should be designed to maintain adequate pressure for all services under the conditions of maximum usage. In order to lay out a distribution system properly certain facts must be ascertained, such as population, area to be served, pressure desired, conditions of terrain, and future growth of city. These facts are important and necessary to determine the amount of water to be delivered, which in turn controls the size of pipe to be laid in the distribution system. The National Board of Fire Underwriters has adopted the following formula for determining the total quantity of water required for fire service.

$$G = 1020\sqrt{P}(1.0 + 0.01\sqrt{P})$$

in which G is the required amount of water in gallons per minute and P is the population expressed in thousands. Table VI shows the fire flows required for cities up to 200,000 population.

In addition to the fire flow, sufficient capacity must be provided for ordinary use, which should be a quantity designated as the average demand of the maximum week. It is generally assumed

TABLE VI.—FIRE FLOW REQUIRED BY THE NATIONAL BOARD OF FIRE UNDERWRITERS

Population	Required Maximum Fire Flow G.P.M.	Population	Required Maximum Fire Flow G.P.M.
1,000	1,000	28,000	5,000
2,000	1,500	40,000	6,000
4,000	2,000	60,000	7,000
6,000	2,500	80,000	8,000
10,000	3,000	100,000	9,000
13,000	3,500	125,000	10,000
17,000	4,000	150,000	11,000
22,000	4,500	200,000	12,000

that 100 gallons per capita per day will be a normal American demand and 150 per cent of the normal rate will represent an ordinary maximum day, while the peak hour rate will be 150 per cent of the maximum day rate, or about 225 gallons per capita per day, Under such conditions the maximum fire demand, based on the Underwriters' formula, plus the average rate of consumption for a maximum day will exceed the peak hour rate of ordinary consumption for cities of less than 270,000 population, and will be less than the peak hour rate for larger cities.

It should be recognized that the fire flow must be concentrated at certain points in the distribution system and at the same time the mains must care for the domestic flow. The fire flows as given by the formula need not, however, be furnished in residential sections but only in the business or high-value districts.

In the preceding paragraph mention was made of water consumption per capita. Hence to obtain total water consumption or demand it is necessary to have population figures. A population study should therefore be made before important water works improvements are made. The decennial United States Census is the most reliable source of information as to the past growth of a city. Supporting data will also be found in the city directory, the number of water customers already on the books, the number of light customers, the number of telephones in service, the number of gas customers, the number of children in grade and high schools. If the ratio of these figures to the population of the census years is found it may be used as a factor to obtain population in years after the last census.

Table VII shows the relationship between water services and population in a number of Texas cities. The census figures of 1930 and the number of meters in service the same year were taken to obtain persons per meter.

For estimating future population it is convenient to plot the population of a city upon a sheet of graph paper, using the available information as far back as possible, to establish the trend of the population increase or decrease. It is then possible to extend the curve following the direction of the past into the future for the required number of years. It should be noted that towns after reaching a certain size have increased in population at a more rapid rate than before reaching that size. To assist in determining the future population curve, it is of value to plot the curves of a few cities larger in size than the city considered, and note the general trend of their development.

Restricted sections of the city must be studied with regard to their possible and probable growth for the period of time being considered. This is particularly important in designing water distribution systems since the mains serve small areas and their sizes will depend principally upon the population in their neighborhood. If the city is divided into wards for voting purposes the population of a given area can be quite accurately estimated from the registered votes of that area.

TABLE VII.—RELATIONSHIP BETWEEN THE NUMBER OF WATER METERS (SERVICES) AND POPULATION IN CERTAIN TEXAS CITIES IN 1930

City	Population	Water Meters	Persons per Meter
Abilene	23,129	6,120	3.78
Amarillo	43,115	9,032	4.78
Austin	53,118	12,077	4.40
Beaumont	57,483	11,047	5.20
Corsicana	15,195	3,300	4.65
Dallas	261,010	61,655	4.24
Fort Worth	163,227	39,579	4.13
Longview	4,991	850	5.86
Lubbock	20,612	4,124	5.00
Marshall	16,190	2,559	6.32
Paris	16,644	3,322	5.01
Port Arthur	49,107	8,611	5.70
San Angelo	25,304	5,518	4.58
San Antonio	254,562	46,772	5.45
Tyler	17,089	2,986	5.71
Sweetwater	10,884	2,182	4.97
Waco	52,825	11,675	4.54
Average			4.96

It has been considered as good practice to plan water works for a period of twenty to thirty years, and to do this, it is necessary to estimate the population that must be served at the end of that period of time.

DESIGNING FOR THE FUTURE.—A definite plan for the development and future extensions of the distribution system is highly desirable. The expected future growth in population plays a very definite part in the establishment of the plan. Knowing the amount of water that will be required in a particular district for fire protection and the amount needed for human consumption, it is possible to design an adequate pipe system to serve the demands. It is not to be supposed that the city will build its distribution system entirely at any one time, but as the population increases and extensions are required, the new lines installed will follow the general plan of the completed lay-out. In many cases, it is possible to use 6- or 8-inch lines to supply a particular territory until it is developed sufficiently to justify the installation of 12- or 16-inch mains, and by having such a program available, it is possible to make use of certain streets for the smaller lines, reserving other streets for the larger lines when the time arrives for their installation.

Character of districts, whether industrial, commercial or residential, and if residential, the density of population, all have important effects upon design. It should also be recognized that future conditions as to character and population density should be foreseen and provided for in the plans.

PRESSURES.—For ordinary service in residential districts pressure of 25 to 40 pounds per square inch are required. Such pressures will not, however, give efficient fire-fighting streams direct from hydrants, and pumpers will be required. In no case, however, should the residual pressure, with a fire in the neighborhood, go below 20 pounds per square inch or domestic demand cannot be adequately supplied to two-story buildings. Occasionally, however, designs were sometimes based upon pressures as low as 10 pounds per square inch in the vicinity of fires.

In high-value districts, particularly commercial and industrial, higher pressures than 40 pounds are desirable and a recent tendency toward normal pressures of 60 to 70 pounds per square inch is noted. This practice has the following advantages: (1) Ordinary consumption will be supplied for buildings up to ten stories in height. (2) Effective sprinkler service is furnished in buildings of four or five stories. (3) Direct hydrant service is given for a few hose streams, thus insuring quicker operation by the fire department. (4) A larger margin of fluctuation is possible in local pressures when meeting sudden drafts, and pressure losses due to partial clogging or excessive elevation of service pipes are offset.

EFFECT OF TOPOGRAPHY ON DESIGN.—It is impossible to give each customer the same pressure at his meter, not only because of the differing length of flow through the mains, with accompanying difference in pressure losses, but also and more especially because of differences in the elevation of the ground on which the city is built. Obviously the pressure will be lower on high ground and higher in the valleys. It has been found economically advantageous in numerous cities to serve the higher portions of the city by means of booster pumps and elevated tanks rather than attempt to raise the pressure over the whole city.

HYDRAULIC COMPUTATIONS.—In recent years, the Hazen-Williams formula for computing flow of water in pipes has come into increasing favor in waterworks practice. The formula is

$$V = CR^{0.63}S^{0.54}0.001^{-0.04},$$

in which the V is the velocity of flow in feet per second; C is the co-efficient of friction; R is the hydraulic radius of the pipe in feet, and S is the slope of the hydraulic gradient. In new pipe the value of C is around 130. In old lines it is lower, sometimes as low as 65, in which case the carrying capacity of the line is but one-half of its original capacity.

The special slide rule designed by Prof. Gardner S. Williams and Mr. Allen Hazen reduces the labor of applying the formula in practical computations. It is manufactured by the Abbot-McKay Corporation of Boston, Mass.

ELEVATED STORAGE.—Elevated storage of water at a point close to the center of draft is valuable to any system. Distribution reservoirs of this type may either be built on high ground or, in the absence of a hill of necessary height, elevated tanks may be used. Storage tanks or reservoirs serve an economical purpose by permitting reduction in costs of plant installation and operation, as well as furnishing a reserve supply for emergency use in case of accident to the water supply or pump station.

The size of the storage reservoir to be provided in any case depends primarily upon local conditions influencing costs. The relations between plant output and storage will vary considerably in different cities, and in the same city in different years, but in cases not subject to extraordinary fluctuations in demand, such as are caused by temporary seasonal influxes of population, the provision of storage sufficient to equalize over the maximum week will frequently be feasible, resulting in limitation of plant capacity to about 130 per cent of the average daily consumption. Storage to equalize over a long period is not often economical, as progressively increasing quantities are required to effect a given reduction in necessary plant capacity. A further discussion of storage and its advantages will be found in Chapter VII.

SEPARATE FIRE-FIGHTING SYSTEMS.—A number of cities in the United States have installed separate systems of mains in the commercial and industrial sections as additional security against fires. The mains are large and the water is under high pressure, sometimes as much as 300 pounds per square inch, thus furnishing large amounts of water to prevent conflagrations. This practice is only economical for large cities having high-value districts. Credits that reduce fire insurance rates are given by the National Board of Fire Underwriters to cities having such dual systems. Where the separate fire systems carry water unsafe for drinking, it is important to avoid cross connections to the regular city mains furnishing water for domestic use. Cities having such cross connections cannot secure state or Federal approval of their water supply.

RECORDS AND TESTS OF PERFORMANCE.—It is also important to keep records of pressure conditions by means of recording gauges at several points in the system. A gauge recording depth of water in reservoirs is highly desirable. Pumping stations should be equipped with a pressure-recording gauge and a recording and totalizing meter to show amounts of water pumped. It has been found very convenient to use fire stations in different parts of the city as locations for recording gauges. Care should be taken in making the installation to see that no other service is taken from the pipe leading from the main to the gauge. Connections to small mains in which the pressure fluctuates widely due to the effect of local draft should also be avoided.

The existence of the records mentioned is very useful in studying the performance of the system during large fires, and helps in running down the causes of peculiar conditions that frequently occur in operation. Bad breaks in mains in out-of-the way places, for example, have been found by making daily inspection of the pressure charts. The records should be supplemented periodically, getting 24-hour records of pressure tests at important points in the system. With the hourly rate of consumption known during some period, curves can then be plotted which will show the capacity of the feeder system for varying rates of draft, and will point out the location where reinforcement is needed.

LEAK PREVENTION.—The well managed water works keeps the unaccounted-for water to a minimum and the superintendent knows at all times what proportion of the whole pumpage comes in this class. It is the difference between the amount of water pumped, as shown by a meter at the pumping plant, and the total shown by the customers' meters plus public use and other authorized and known uses. It is made up of leakage and unauthorized uses and should not exceed 20 to 25 per cent of the total pumpage. Some cities inaugurate a leak survey when the unaccounted-for water exceeds the percentages mentioned. Methods of making leak surveys are given in the following article.

The actual site of a leak in a main can be found in various ways. In unpaved streets a steel rod may be driven into the soil and withdrawn to see if it is wet. Driving the rod into the ground until it rests against the main at various points and placing the ear or teeth against the upper end will allow the observer to tell by the vibration whether he is close to the leak. The various phone-like devices used as leak detectors also depend upon the fact that the escaping water sets up vibrations in the main which are transmitted to hydrants, service boxes, etc. Such devices are also used to detect leaks in the plumbing systems of unmetered services.

In order to make repairs or changes to water mains, pipe locaters are sometimes useful. The simplest consists of a magnetic dip needle which dips when held over iron or steel. It is not dependable, however, where the pipe is deeper than about 18 inches. The General Electric Company makes a more elaborate magnetic device which will locate pipe buried several feet underground and which also allows estimation of the depth of burial. Magnetic devices, however, have the disadvantage in large cities of being interfered with by other buried metal pipes.

FLOW TESTS IN THE DISTRIBUTION SYSTEM.—The hydrant flow test is a method of testing a small portion of the system. This method involves the observation of the effect upon residual pressures in a given locality while discharging measured quantities of water from nearby hydrants.

It is frequently advisable to check the system to discover major leaks and unauthorized uses of water. Hydrants may also be utilized for this purpose. All valves are closed leading to a restricted section and water is fed to the area through a fire hose connecting two fire hydrants. A large meter measures the flow through the hose. The test is made at night when domestic demand is low and the existence of a large flow indicates a leak. The test may also show large unauthorized uses, as illegal taps made by unscrupulous persons for industrial uses.

The pitometer (see Chapter VI) is a simple, portable device for measuring the velocity of flow in pipes. It may be used to check the flow in certain mains, or systematically over the whole system to discover leaks or other water losses, to determine the interior condition of pipes and to locate closed or partially closed valves. Valves are closed on all feeders but one of an area and the velocity in the single main is determined by the pitometer. The night flow is most indicative of abnormal conditions. Engineering firms specialize in conducting pitometer surveys over the complete system of mains. They frequently find unsuspected leaks that are wasting millions of gallons of water daily. In the larger systems, it is desirable to have permanent gauging stations installed in the primary feeders for the determination by pitometer measurement of the distribution of consumption among the several principal districts of the city.

LOCATION OF MAINS.—Water lines in a distribution system usually follow the city streets or alleys. The practice of locating mains on easements across private property is to be discouraged, and should be used only when other locations are lacking. Assignment of space for water pipe in streets or alleys should be secured from the city engineer to eliminate the possibility of conflicts with other utilities. In any case the mains should be placed low enough in unpaved streets so that they will not interfere with future paving. The mains should also be buried deeply enough to insure against freezing in the cold climates. Only sufficient cover will be needed in the warmer climates to give protection against traffic and ground erosion, usually not less than 24 to 30 inches.

A practice that is increasing in popularity is the use of the 2-main system. In Chicago, for example, the practice has become standard in all streets 80 feet wide or over or having double-track street railway lines. A water line is placed on each side of the street between the curb and the sidewalk. The main on one side is large enough to supply the fire flow and all hydrants are located on it. The other main may only be 2 inches or 4 inches in size and merely supplies domestic demand on its side of the street. Connections are made at the street intersections to the large main. This arrangement has the advantages of reducing the length of the service pipes and eliminating damage of street paving when placing, replacing or repairing services. Under some conditions the saving in cost of services more than offsets the cost of the extra main.

JOINT MATERIALS.—The poured and calked lead joint is still considered as standard, although many Texas cities use the sulfur base compounds, sold under the trade names, Leadite, Hydrotite, etc. The lead substitutes, when properly handled, make excellent joints, but if overheated the material is valueless. The initial leakage is large, but after a reasonable length of time it has been found to have less leakage than lead joints. Lead should always, however, be used in the joint connecting a line laid with lead substitute to an old line. The flexibility of the lead permits the settlement of the new line without a broken joint. The lead substitutes, on the other hand, make a very rigid joint. Standard specifications for sulfur base compounds are not available.

Portland cement mortar joints are successfully used by some California cities. A very dry mortar of 1 part cement to 1 part sand is used. A test as to proper consistency is that it should ball when squeezed in the palm of the hand but fall apart when the ball is dropped a distance of 1 foot. The joint is yarned and then half filled all around with mortar rammed in as tightly as possible. Then the joint is completed with more mortar also tightly rammed. There is some initial leakage but this soon ceases.

TESTING OF NEWLY LAID MAINS.—New mains should be tested under a water pressure at least 50 pounds greater than the normal operating pressure. The joints should not be covered before testing and the backfilling between joints before testing should not exceed 6 inches above the barrel of the pipe. The pipe should be allowed to fill slowly with water and all air allowed to escape through open fire hydrants or special plugs at high points. After all air has been expelled the valve or valves leading to the old section of the system are closed. Pressure is then applied by means of a hand pump in the case of small lines, or small sections of large lines, or by the use of a gasoline pump or fire pump in the case of large lines. A meter should be located in the pump discharge so that when the pressure is up to the specified point all water going into the pipe and lost by leakage can be measured and recorded. While the pipe is under pressure it should be thoroughly inspected both as to the pipe and the joints. Leaking lead or lead-wool joints can be repaired by additional calking. Joints of lead substitutes are not tested until several days after the pipe is filled as they will leak for a time before taking up. If bad joints are then found the material is cut out and replaced. Specifications as to allowable leakage in new mains are likely to restrict it to less than 100 gallons per 24 hours per mile of pipe per inch of nominal diameter for 12-foot lengths, and 75 gallons for 16-foot lengths.

VALVES.—Gate valves should be so located in the distribution system that no single break or repair in the system, exclusive of main arteries, will necessitate shutting off more than 500 feet of main in the high value districts and 800 feet in the other sections. It is advisable to locate all gate valves at some uniform point for ease of location. Since the valves are generally at street intersections, they may be located where the property line of the corner lot, if extended, would intersect the main.

All valves should be inspected yearly and the large ones more frequently. The inspections should include the condition of the box and presence of stones within it. Before operating the valve itself a small amount of kerosene should be poured down the stem to lubricate the stem against the packing gland and soften the packing. Then operate the value up and down several times, bring the gate down into the groove hard each time and then open the valve each time about one-quarter way. This procedure, by increasing the water velocity over the groove will usually dislodge rust or other sediment that may prevent the valve from seating tightly. Care should be taken that the valve is reopened completely after inspection and to insure this it is well to note the number of turns required by a valve of given make and size for complete opening.

Check valves are used to permit water to flow in one direction only. They are usually placed in the discharge lines of pumps. If not in frequent use, as in a line from an emergency pump, inspections should be frequent. Check valves can be obtained for both vertical and horizontal positions. A check at the lower end of a pump suction is known as a foot valve.

Pressure regulating valves are used to deliver water from a high-pressure system to a low-pressure system. They include a lever operated from a pressure chamber that tends to close the valve when the pressure on the low-pressure side becomes too great. They can be regulated to obtain the pressure differential required.

Balanced valves are used on pipe lines which operate under high pressure. They are so arranged that pressure is exerted on both of two disks which balance each other, thereby permitting easy opening and closing of the valve.

FIRE HYDRANTS.—Spacing of hydrants should conform to the requirements of the National Board of Fire Underwriters or the State Fire Insurance Commission if the minimum insurance key rates are to be obtained. Table VI gives the required flows, and the hydrant spacings are related to those flows. The average area served by a hydrant varies from 120,000 square feet for a required fire flow of 1000 gallons per minute to 40,000 square feet for a flow of 12,000 gallons, with use of engine streams. If dependence is placed upon direct streams from the hydrants the average area served by a hydrant should not exceed 120,000 square feet for a fire flow of 1000 gallons and 40,000 square feet for a fire flow of 5000 gallons or over. Practically speaking this means that the required number of streams, assuming each to be 250 gallons per minute can, with motor pumpers, be obtained with hose lines averaging not over 300 to 400 feet in length. It also means that in residential districts hydrants will be needed at street intersections, with spacing never exceeding 600 feet, and in business sections with hydrants at street intersections, also spaced at the midpoints of blocks and preferably in alleys also.

Hydrants consist of the following parts: the elbow, which connects with the pipe leading to the water main; the vertical pipe or barrel; the head, which includes the operating nut and a stuffing box; and the main valve, with its stem and appurtenances. The main valves are of four types: one in which a disk rises vertically upward against a horizontal circular seat; a similar type in which the disk moves downward against the seat; another in which the valve disk moves horizontally against the seat; a fourth in which the disk slides vertically in grooves in the same manner as a gate valve.

Hydrant size is designated by the diameter of the valve opening. The valve opening should be at least 5 inches in diameter. The area of the barrel should be at least 120 per cent of the valve opening area. Hydrants should never be placed on pipe branches less than 6 inches in size and the branch should have a gate valve. Hydrants should be able to deliver 600 gallons per minute with a loss of head of not over 2.5 pounds in the hydrant and 5 pounds from the street main to the outlet. They should have not less than two 2.5-inch outlets and also a large connection where a motor pumper is necessary. Hydrant design should be such that when the barrel is broken the valve remains closed. A drain that allows escape of water in the barrel after the valve is closed is provided. Where freezing is to be expected a bed of crushed stone or gravel is placed around the hydrant to allow drainage water to seep quickly into the soil.

Hydrants should be inspected at least twice and preferably four times a year. The inspection should cover tightness of the nozzle caps and tightness of the drain valve while main valve is open. The efficiency of the drain valve in draining the barrel after the main valve is closed should be noted. Note also whether the main valve shuts off completely. It is highly desirable to test the pressure loss while the hydrant is flowing. After testing the valves the stem should be oiled and the nozzles greased with a graphite grease. Hydrants should be painted annually. A card should be filed for each hydrant showing make, size, pressures and rates of flow, inspections and repairs.

SERVICES.—The water service is commonly understood to mean the connection to the main, the pipe leading from the main to the cutoff at the curb meter, the meter box, the property owner's cutoff and box, and the pipe leading from the meter to the house. Both the water department and the property owner have very definite rights in the service. In the great majority of cities in Texas, the meter is the dividing line between the water department and the property owner, and where meters are installed at the curb or property line, it is customery for the property owner to maintain the line from the meter to the house, and the water department from the main to the meter.

Galvanized steel and wrought iron, lead, cast iron, copper, and brass are used for service piping. Galvanized steel pipe services are probably the most common. They are strong and comparatively cheap, but some waters and soils cause them to deteriorate rapidly. They often become clogged with rust to such an extent as to impair service. Lead pipe has the advantages of not rusting or decreasing in carrying capacity, and it may be curved in a trench. Its disadvantages are its comparatively high first cost and the fact that some waters dissolve enough of the lead to cause injury to health of the consumers. Cast iron is a durable metal for services, and may be had in commercial sizes from 1¼ inch up, although the sizes below 2 inches are not generally considered as entirely satisfactory. In recent years, the development of copper tubing and practical connecting fittings has resulted in a great increase in the use of this material. Copper service pipe offers the following advantages: (1) uniformly good carrying capacity over a period of years, due to lack of tuberculation; (2) reasonable initial cost, less than lead although higher than galvanized iron; (3) joints are easily made; (4) ease of handling; (5) less storage space required; (6) ability to withstand intermittent freezing and thawing; (8) flexibility; (9) ability successfully to withstand corrosion.

The type of material to be used in services should be decided after consideration of the character of the water and soil and possible length of life. Leaky services may mean expensive and unsightly repairs to paved streets. Many cities make a practice of replacing all iron services with copper, brass or cast iron before paving streets.

Consideration should also be given to the size of service to be installed and to the services that are already installed. Architects and plumbers frequently prescribe too generously in this respect. Properly graduated installation and service charges for different size connections and meters tend to diminish the incentive for over-servicing, and to repay the water department for the facilities granted. The size of the service pipe generally may be one size larger than the meter, for instance: ¾-inch pipe should be used with a ⅝-inch meter. If the line is long it should be increased to reduce friction and permit the flow to be at full meter capacity.

Opinions differ regarding the desirability of installing services at vacant property in advance of permanent paving. In territory where the type of building construction is fairly well established, it is safe to install services for vacant lots. Where the territory has not been sub-divided, the problem is more difficult, although water service is generally not required in undeveloped territory. In warehouse or industrial districts it is impossible to forecast the size of the service needed. Consequently, it will prove economical in the long run not to stub out any services. It is apparent that the two-main system simplifies this problem.

SERVICE METERS.—Since the water works depends for its revenues upon the sale of water to consumers it is highly important that all services be metered so that the cost of service can be properly apportioned. It is almost equally important that the meters be properly maintained. Meter sizes are designated according to the size of inlet and outlet pipe. Specifications for meters have been formulated by the American Water Works Association (see Appendix B).

For services up to and including 1¼-inch pipe size the disk type meter is most commonly used. The disks are of hard rubber, usually reinforced with metal or having a thrust roller to take the thrust of the water and prevent damage to the disk. The disk rolls in a chamber as the water passes through, a single roll indicating a volume equal to that of the chamber. A spindle transmits the movement of the disk to the gears above. The register may show the amount of water passing in cubic feet or in gallons. The rubber disks will not withstand hot water and check valves must be placed in hot water systems to prevent backing up of hot water to the meter.

The gear train may be oil-enclosed or open. The oil-enclosed type has the advantage of operating with less friction but it may freeze in cold climates because of small amounts of water trapped in the enclosure. For cold climates the open train is recommended.

While disk meters can be obtained in sizes up to 6 inches, other types are commonly used for flows over the normal rating of 2-inch disk meters. The larger meters are usually of the current type, in which the water passes through a series of curved blades or vanes that are attached to a shaft which turns at a rate proportional to the flow of the water. Meters of this type are made in sizes up to 12 inches.

Compound meters are used where the rates of flow are widely varying. They usually consist of a disk meter which takes the low flows, which otherwise would not be accurately registered. When the demand becomes heavy the flow is automatically diverted to the large meter which is of the current type.

Meter sizes should be adopted according to the amount of water that will be used. Table VIII will be a guide in choosing sizes to be used. The use of oversize meters is to be avoided.

The maintenance of water meters includes not only the repairing of damaged meters but testing them to ascertain whether they are still accurate. Since the inaccuracy is almost invariably under-registration testing is a matter of economy. If the cost of testing and subsequent reworking of the meters is less than the value of the unregistered water the work will increase revenues. Routine testing at certain intervals will, therefore, pay dividends, the interval depending upon local conditions, character of the water, etc. It may be that 5-year intervals will be found advisable or even 10 years. In any case a record should be kept for each meter, showing repairs and results of tests. The test is essentially a measurement of water passed through the meter and a noting of the amount registered.

TABLE VIII.—REGISTRATION REQUIREMENTS FOR METERS A. W. W. A. SPECIFICATIONS

Size	Normal test flow limits, gal. per min.	Minimum test flow, gal. per min.	Gal. per min. at 25 lb. lost head
5/8	1 to 20	1/4	20
3/4	2 to 34	1/2	34
1	3 to 53	3/4	53
1 1/2	5 to 100	1 1/2	100
2	8 to 160	2	160
3	16 to 315	4	315
4	28 to 500	7	500
6	48 to 1,000	12	1,000

TAPPING.—Water mains are tapped for service connections at any convenient angle from the vertical to the horizontal. Connections below the 45-degree position have proven generally the most favorable in that there is less liability of the corporation cock being injured.

Care should be taken in inserting the corporation cock. The pipe should be drilled so that the end of the corporation cock does not protrude more than 1/4-inch beyond the inside of the main. The corporation cock should be screwed in only sufficiently tight to allow the removal of the tapping machine. After the tapping machine has been removed, then the cock may be set with a wrench just tightly enough to allow the proper use of the cutoff. A corporation cock inserted too tightly in the main may cause the main to break.

CURB COCKS.—Every service should have a cutoff at the curb line to be used only in case of emergency by the water department or by those authorized by the department. The property owner's cutoff should be of the stop-and-waste type. It is preferable to have the property owner's cutoff on the house side of the meter so that any hot water to be drained from the pipe will not pass through the meter. This, of course, necessitates the installation of the meter sufficiently deep to insure against freezing.

PREVENTION OF HEALTH HAZARDS IN THE DISTRIBUTION SYSTEM

SAFEGUARDS IN CONSTRUCTION.—Precautions against contamination of water in the distribution system should start with location of the mains and service pipes. A water line should not be located in the same trench as a sewer, except where rock cuts are encountered, and under such conditions the water line must be laid on a shelf cut in the side of the trench. When a sewer is less than 10 feet horizontally and 6 feet vertically from a water line, or when a sewer and water line cross, all that part of the sewer within 10 feet horizontally and 6 feet vertically should be of cast-iron pipe with calked lead or other tight joints.

Before excavation for water pipes is begun the location of sewers should be ascertained and located on the ground. The excavation should be conducted so that the contents of a sewer will not be discharged into the ditch of the water line. Sewers within the distances given in the preceding paragraph should be relaid as there specified. Sanitary conveniences should be furnished so that workmen will not use the ditch for defecation or urination.

Water pipe should be cleaned of foreign matter before it is lowered into the ditch and it should be kept clean during and after laying. No trench water should enter the pipe and the open end should be closed at all times when laying is not in progress.

DISINFECTION OF WATER MAINS.—Prior to disinfection new mains should be thoroughly flushed through the fire hydrants. Any of the following disinfection methods may then be applied. Care should of course be taken that not only mains, but valves and other appurtenances are also disinfected.

A mixture of chlorine gas and water may be applied by means of a solution-feed chlorinating device. The point of application of the disinfecting solution should preferably be at the beginning of a pipe line extension, or any valved section of it, and through a corporation cock inserted in the horizontal axis of the newly laid pipe. The water injector for delivering the gas-water mixture into the pipe shall be supplied from a tap on the pressure side of the gate valve controlling flow into the extension. Water from the distribution system as it enters the new line must be controlled to flow slowly during the application of the chlorine and the gas-water flow entering shall be in such proportion that the treated water entering the newly laid pipe shall have a concentration of not less than 40 to 50 parts per million of chlorine. The chlorinated water should be retained at least 3 hours and preferably longer and at the end of the retention period the chlorine residual should be not less than 0.5 part per million. Following disinfection the treated water should be flushed from the main before it is placed in service and bacteriological tests of water in the refilled main should be made to determine the efficiency of the disinfection.

A solution of calcium hypochlorite (chlorinated lime) may also be used. The chemical is first made into a paste and then thinned with enough water so that the resulting mixture will be 5 per cent by weight of chemical to 95 per cent of water. The liquid is pumped or injected into the newly laid main under the same conditions as indicated for a gas-water solution. The chlorine content, retention, testing and flushing should also be as previously prescribed.

Dry calcium hypochlorite or other form of chlorine compound may be placed in the pipe as it is laid. This practice has the disadvantage of preventing flushing of the pipe preliminary to disinfecting. The amount of calcium hypochlorite (65 per cent available chlorine) necessary for various sizes of pipe will be found in Table IX. The dose is shaken into the pipe as a powder or in capsule form at the first joint of the new main and repeated at intervals of not over 100 feet, and preferably less, as the pipe laying progresses. When this method is used the new pipe should be filled with water very slowly to avoid washing the powder to one end of the line. Retention, testing, flushing, etc., should be carried out as previously prescribed. If the bacteriological test after disinfection by any means is unsatisfactory the same or an alternate procedure should be followed.

Cuts made in a pipe line for inserting of valves or fittings, making of repairs, or for any other purpose should be followed by disinfection by shaking a dry chlorine compound in the pipe on each side of the cut in sufficient quantities to obtain a 0.5 part per million residual. After slowly filling the section and reversing the flow the chlorinated water should be retained as prescribed above and then flushed out.

TABLE IX.—DOSAGE OF CALCIUM HYPOCHLORITE * PER 20 FEET OF PIPE TO GIVE 50 PARTS PER MILLION OF AVAILABLE CHLORINE

Nominal pipe size inches	Calcium hypochlorite ounces	Nominal pipe size inches	Calcium hypochlorite ounces
4	⅛	20	3½
6	⅓	24	5
8	⅝	30	7¾
10	⅞	36	11⅛
12	1¼	42	15¼
16	2¼	48	20

* Available chlorine 65 per cent.

CROSS-CONNECTIONS.—To the water works man a cross-connection is a physical connection to another water supply, to a tank or reservoir, or to a plumbing fixture or other appurtenance, by which polluted, contaminated or otherwise undesirable water may enter the public distribution system.

A common type of cross-connection is the private water supply of an industrial plant or other business building with a pipe connection to the public supply. Sometimes the private supply is for fire protection and admittedly is unsafe. In any event the fact that the private water supply is not under public supervision makes the arrangement dangerous. If the water pressure in the private supply is greater than that of the public supply there may be leakage of unsafe water into the city mains. Furthermore, arrangements of gate and check valves do not give adequate protection, for they will invariably leak sooner or later. Dependence upon valves in any case will place a burden and expense upon the city for inspections and tests. The U. S. Public Health Service and the state health departments will not give complete approval to water supplies where cross-connections of this type are known to exist.

The industrial plant which desires the advantage of a dual supply from the city may obtain it by discharging the city water into a tank from an outlet pipe that is at least 6 inches *above* the maximum water level of the tank. A float-controlled valve may be placed on the city supply pipe to keep the water tank level at the desired point.

The second type of cross-connection is exemplified by a swimming pool where make-up water from the city supply is discharged into the pool below the water level. Under such circumstances it is easily possible for water to be siphoned from the pool into the city mains. The remedy here is to discharge the new water from a pipe that terminates at least 6 inches above the edge of the pool. Pools which recirculate water may also have a cross-connection to the recirculation system that permits washing of the pressure filters with city water.

The third type of cross-connection is very commonly found in plumbing fixtures. All fixtures which have water inlets below their overflow levels may, if the water pressure is off and the fixture is full of water, permit siphonage into the supply pipes. This sanitary defect is frequently found in bathtubs, lavatories, glass washers at soda fountains, slop sinks and bed pan washers at hospitals, sterilizers, drinking fountains, etc. Flushometer valves on toilets and urinals will permit back-siphonage when there is no stoppage of the outlet. The remedies are termination of water supply pipes at least ¾ inch above the maximum possible water level of the fixture. In the case of toilets and urinals with flushometer valves, only types with acceptable vacuum breakers should be installed.

Allied to cross-connections of the types already mentioned are priming connections to pumps handling sewage or other dangerous liquids; connections to water-cooling and condenser systems; sewer flush tanks where the water inlet may become submerged; pipe lines leading into cisterns for household supplies.

Chapter IX

WATER TREATMENT AND METHODS

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The operator of a water treatment plant is concerned with certain impurities of water, which, if permitted to remain in the distributed water would be objectionable to the public. Means for their removal are available to the operator. It is the purpose of this chapter to name and define these characteristics, indicate how they may be detected, and describe how the tools for water treatment can be used properly to prepare the water for public use.

Turbidity and Its Removal.—When a water is not clear it is said to be turbid, a condition caused by the presence of one or more of such materials as clay, fine silt, and small dead or live plant organisms. Every plant should keep a daily turbidity record of the raw water, settled water, and water delivered to the mains. Particularly helpful is the record of water delivered to the mains, for invariably where there is turbidity there are bacteria.

Keeping of records requires measurement of turbidity. The standard unit of measurement for turbidity is considered as that produced by 1 part per million of fine silica (1 pound of fine sand in 1 million pounds of water). For turbidities above 25 parts per million use prepared standards in clear glass bottles. The settled water in a treatment plant should nearly always come within this range. For turbidities below 2 parts per million use the Baylis turbidimeter. The turbidity of water going to the distribution system comes within the range of this instrument. See Chapter XVI for methods of turbidity measurements.

When the chemical treatment is correct the water going to the sand filters should not have a turbidity of more than 15 parts per million. Turbidity of water delivered to mains should not be over 0.5 part per million, since turbidity values below 0.5 cannot be readily detected by the consumer.

Turbidity of water may be removed by the addition of coagulants, such as alum (aluminum sulfate) ($Al_2(SO_4)_3 \cdot 18H_2O$); iron sulfate (ferrous sulfate) (copperas) ($FeSO_4 \cdot 7H_2O$) and lime, (CaO) or ($Ca(OH)_2$); chlorinated copperas, which is iron (ferrous) sulfate ($FeSO_4 \cdot 7H_2O$) plus chlorine to make ferric sulfate ($Fe_2(SO_4)_3$) and ferric chloride ($FeCl_3$). All of these chemicals or combinations of chemicals form a heavy gelatinous floc which settles to the bottom of the coagulation-sedimentation tank, carrying with it most of the turbidity.

The best way to determine how much chemical is necessary to coagulate turbidity in a given water is to make the "jar" test (see Chapter XVI). If a laboratory is not available, a rough method will be helpful. Procure two or three 5-gallon water bottles. Fill each with raw water and add 1 grain per gallon of alum to one bottle (as much alum as will remain on the tip of an ordinary case knife). Stir with a stick as rapidly as possible for 10 minutes. If the particles are large and settle rapidly and the water is fairly clear after 1 hour, 1 grain of alum is sufficient. If this does not seem to be the proper amount of alum for coagulation, an additional quantity of alum such as 2 grains, 3 grains, etc., can be used, proportioned on the same basis as the 1 grain. When the proper dose is thus determined, the coagulant can be added at the same rate in the plant. For each 1000 gallons of water to be treated with 1 grain per gallon of alum add 2.25 ounces of alum. For example, if 1 million gallons of water is to be dosed at the rate of 2 grains per gallon the total amount required would be $1000 \times 2 \times 2.25$ or 4500 ounces (281 pounds) of alum.

Lime and iron sulfate doses can be determined in a similar manner. Chlorinated iron sulfate can be tried but application should be under the supervision of some one experienced in using this type of coagulant.

Every treatment plant should be provided with some means of measuring the flow of water into the treatment basins, together with accurate feeding machines so that the chemicals may be properly proportioned. The alternative, guessing at the flow and applying the chemicals by hand methods is wasteful and unsatisfactory. Dry feeders are inexpensive and any treatment plant, large or small, can afford proper equipment for feeding chemicals.

Aluminum sulfate or "alum" is commonly used alone in the treatment of water and is a coagulant satisfactory for a large number of different types of water. It works best when the water has a pH of below 7 and above 10. Between these values a larger quantity must be used, for the alum floc is liable to go into solution and therefore be ineffective. Lime is added to the water to give alkalinity, if it is not already present, in order to cause the flocculent precipitant. The lime will also make the water more stable after the alum treatment.

Aluminum sulfate is manufactured and sold in large quantities for water purification use by several large firms. The American Water Works Association has set up standard specifications for alum and when large quantities are purchased, it is advisable to use them. In Appendix B will be found the sources for standard specifications for alum and other chemicals.

Within the last few years an innovation in the form of a coagulant has appeared on the market, known as "black alum." This is aluminum sulfate to which a small percentage of activated carbon has been added and thoroughly mixed. Claims are made that the carbon addition improves the coagulating effect of the aluminum sulfate and also that the activated carbon dose may be added in this way for taste and odor control. The mixture of the two materials offers some disadvantage in that the operator is unable to vary each independently of the other. It must be borne in mind that good control of feeding processes requires that each chemical be fed by itself.

Iron (ferrous) sulfate, also known as copperas, when used with lime usually works fairly well at all pH values of the water, although above pH 10 the reactions produce a larger floc. Ferric iron salts are on the market but have yet to prove their value as substitutes for the older coagulants in water treatment. Ferric salts with lime, however, appear to work better than ferrous salts on many waters. Complete solution and sufficient time for mixing are important items.

Ferrous sulfate is not manufactured in as large quantities as aluminum sulfate, very largely because it is not as extensively used. At present, therefore, competitive bidding among sellers is difficult to obtain. An important specification on this material is that it be acid free, thus insuring freedom from lumps and making it easy to feed in the dry feed machine.

Sodium aluminate is prepared commonly by combining alum with caustic soda. This material has high coagulating power and produces some softening action on the water treated. It is of particular value in treating colored waters. Its advantages in treating the usual municipal waters do not justify its very high cost.

Where lime is used in proper dosages and where the raw water contains an appreciable amount of magnesium, a large proportion of the magnesium is changed into a bulky flocculent mass which will be very effective in reducing turbidity. Better coagulation can be realized this way than with any coagulant added. The bulk of such a precipitate formed may be from 10 to 20 times as great as can be obtained by the use of the ordinary coagulants.

Lime may be purchased as hydrated lime or as quicklime. The lime producing companies will crush bulk quicklime to any size desired without extra cost. If the use of lime is large and the equipment permits, the use of quicklime in bulk is the most economical. Quicklime in bags will not store over six months without slaking and bursting the bags, thus making it inconvenient to store much material. Standard specifications for lime are available and should be used. An equitable requirement for Texas lime is a calcium oxide content of not less than 90 per cent. Terms frequently made are in the form of an agreement whereby the lime company will be paid a bonus of 1 per cent over the contract price per ton for each 1 per cent by which the water-soluble CaO in any car-load lot delivered shall exceed 90 per cent and the city shall deduct a penalty of the same amount for each 1 per cent under 90 per cent. Also, a requirement as to freedom from unburned limestone and cinders should be inserted. When specifying hydrated lime, a content of 70 per cent CaO is acceptable.

Hydrated lime can be added directly to the water by dry-feed methods. Quicklime, lump or pulverized, should be slaked in slaking compartments before being added to the water. Attempts to add pulverized quicklime directly to the water are not as satisfactory as when the lime is first hydrated or slaked.

In using all coagulating chemicals, including lime, it must be remembered that their reactions to form the floc or other required effect are far more rapid and complete at 80 degrees F. than they are at 40 degrees F. and below. This effect of temperature on speed of chemical reaction in plant operation is quite noticeable. Longer mixing and settling should therefore be provided in winter than in summer. Reactions, particularly of lime, are further discussed under water softening.

DISINFECTION.—Coagulation, sedimentation, and filtration will remove practically all turbidity from water and nearly all the bacteria. Under most conditions such treatment will make a water safe. A final disinfection, however, adds a factor of safety that is absolutely necessary. If the raw water is very highly contaminated final disinfection may be necessary to insure that the effluent will conform to the U. S. Public Health Service Standards. Chlorination is the common disinfection method used. It is discussed in Chapter XI.

COLOR AND ITS REMOVAL.—Color in water is usually due to vegetable organic chemical compounds resulting from the infusion of the leaves and bark of decaying vegetation. Swamp water is generally highly colored due to the presence of decayed vegetation which has been in contact with the water. Iron compounds will often be the cause of color. Waters carrying considerable clay and mud are, as a general rule, free from color, as the clay particles tend to adsorb any color which may be present in the water. If color is present in the raw water it is quite desirable to keep a record of the amount present. Apparatus necessary and the method for making the determination will be found in Chapter XVI.

Color is removed by means of coagulation. E. S. Hopkins[1] states, "Coagulation of colored waters has been a problem only recently successfully solved. It is believed that these waters coagulate best when slightly acid or with low pH values. . . . If this acid condition is neutralized before the addition of the coagulant, particularly when alum is used, the formation of the color floc is retarded and the color set." The recently developed method for the removal of color from waters having a low pH is a split treatment. First, chlorinated copperas is applied in sufficient quantities to give a good floc. Half way through the mixing an alkaline coagulant is added. This may be alum and lime, or chlorinated copperas and lime.

IRON.—Quite often it is necessary to deal with waters containing ferrous iron. The presence of iron in appreciable quantities can usually be detected by the physical appearance of the water, a cloudiness developing on standing, or the formation of a yellow or brown precipitate. Iron in small quantities in water not thus detected can be determined by chemical analysis of the water.

To remove iron from water the aeration methods, as described in Chapter X, followed by sedimentation and filtration through sand beds, are both simple and effective. With some waters coagulation with lime is found to be necessary before sedimentation. Aeration by allowing the water to trickle through coarse coke beds will not only furnish oxygen to oxidize a considerable amount of iron but will also hold a large part of the precipitated iron in the bed.

MANGANESE.—For a long time many have taken it for granted that iron and manganese are similar since they very often occur together in water. While the two may be present in a water supply, they are quite dissimilar, manganese being much more troublesome than iron, even in very small quantities. If a raw water contains manganese, plant basins, filters, and mains will often show black slimy coatings or stringy black deposits. These black deposits will produce stains wherever the use of water in processing materials has the opportunity to show such action. Thus, the laundry industry is seriously affected by having clothes stained, and bleaching and dying processes are interfered with. The individual consumer, of course, also has his problem in laundrying activities.

Manganese is frequently found in ground water and occasionally it is found in surface waters. Manganese compounds go into solution through the decomposition of organic matter in soils containing manganese, and in the absence of oxygen, so that manganous compounds are formed. When the water containing these manganous salts is removed to conditions where there is plenty of oxygen, the manganese is precipitated as a manganic salt which is insoluble in water.

The history of manganese in water supplies is comparatively meager and of late development. There are many views relative to the various angles of the problem. Zapffe,[3] in writing a history of manganese in water supplies and methods for its removal, attempted to divide the work of investigators into the following periods: (1) The bacteriological period, 1836–1906. (2) The period of inorganic chemistry, 1906–1914. (3) The period of physico-chemistry, 1914–1922. (4) The period of catalysis, 1922–1930. (5) Present practice, 1930.

A typical installation using no chemical treatment is to be found at Lincoln, Neb.[4] The water, which comes from wells, contains 0.25 to 1.25 parts per million of manganese and 0.30 to 0.60 parts per million of iron. This plant comprises the processes of aeration, chlorination, upward-flow contact filtration, 2-hour sedimentation, rapid sand filtration, in the order named.

In plants where water softening is undertaken, no troubles with manganese and iron are experienced. All investigators agree that both iron and manganese are readily removed by the water-softening processes. Accordingly where lime, or lime and soda, are used along with coagulation, there need be no concern about the presence of manganese in the finished water.

At Baltimore, where the water contains 1.0 part per million of manganese, and softening is not necessary, the method used includes precipitation with iron sulfate and lime, followed by sedimentation and filtration. Alum has proved to be quite unsatisfactory as a coagulant for this purpose. In chemical treatment the pH of the water is kept above 9.0. Authorities agree that any amount of manganese over 1.0 part per million is objectionable and if such amounts are present waters should be subjected to some sort of treatment for its removal. For the method of estimation of manganese in a water see Standard Methods of Water Analysis, 8th Edition, 1936.

TABLE X.—HYDROGEN SULFIDE LEFT IN SOLUTION AFTER AERATION BY EXPOSURE IN DROPS

Time	Hydrogen sulfide parts per million	Odor
At start	15.2	Faint
After 1 second	10.2	Very faint
After 1.5 seconds	5.0	Very faint
After 2.0 seconds	2.6	None

HYDROGEN SULFIDE.—This gas may occasionally be found in waters that are highly mineralized and where decomposition of organic matter has taken place. This impurity can very easily be detected by its characteristic odor of rotten eggs. Hydrogen sulfide gas can be readily removed from water by the use of spray nozzle aerators. This treatment breaks the water into droplets and the gas escapes to the air. Table X shows the efficiency of such a method.[5]

CARBON DIOXIDE.—Carbon dioxide is dissolved in the water from the air, but it is also derived from decaying vegetation and plant by-products, either in the soil or from decaying organic matter in swamps, ponds, etc. For the detection of free carbon dioxide in water, note the tests given for carbon dioxide in Chapter XVI. As with hydrogen sulfide, carbon dioxide may be removed partially by spray aeration. Table XI shows the efficiency of such a method.[5]

TABLE XI.—CARBON DIOXIDE LEFT IN SOLUTION AFTER AERATION BY EXPOSURE IN DROPS

Time	Carbon dioxide, parts per million			
At start	5.0	10.0	25.0	50.0
After 0.5 second	4.1	6.9	13.8	23.4
After 1.0 second	3.5	5.3	9.3	14.0
After 2.0 seconds	3.0	4.1	6.2	8.5
After 5.0 seconds	2.5	3.0	3.8	4.5
After 15.0 seconds	2.1	2.1	2.1	2.1

When lime is added to water in softening treatment or when it is added for raising the pH, free carbon dioxide is removed completely. Alum used as a coagulant, without addition of lime or other alkali, will produce carbon dioxide. This will not only add to the corrosiveness of the water but, if other conditions are favorable, will offer an attractive inducement to algae for their growth, as carbon dioxide is an important food supply for plants of all kinds, including the algae.

FLUORINE.—Only in very recent years has the presence of fluorine in water attracted the attention of public health officials. The fact is now well established, however, that waters containing fluorine in excess of 1.0 part per million have produced on the teeth of young children during the early years of dental formation an effect known as mottled enamel, this effect being a chalky appearance, a slight discoloration, or an intense dark discoloration, with a crumbling of the tooth substance. To date areas of the United States known to have waters causing this trouble are to be found in the following States: Arizona, Arkansas, California, Colorado, Idaho, Illinois, Kansas, Minnesota, Mississippi, Nevada, New Mexico, North Carolina, North Dakota, Oklahoma, Oregon, South Carolina, South Dakota, Tennessee, Texas, Utah, Washington, Wisconsin, and Virginia. In Texas, the Panhandle and neighboring parts of west Texas constitute the largest mottled enamel area in the United States. An area of unknown size is also reported in east central Texas between Austin and Dallas.[6] Information to date indicates that fluorine is found only in well waters and not in surface supplies. The analysis of water for an accurate estimation of fluorine requires considerable skill and should be attempted only by trained and experienced chemists having adequate laboratory facilities at hand. If it is desired to make an estimation of fluorine, a very satisfactory method is given in Standard Methods of Water Analysis, 8th Edition, 1936. Much investigation in this field is needed for as yet no satisfactory treatment has been discovered to remove fluorine from a water supply. Experiments with addition of magnesium oxide to the water appear to be promising, although more experiment is needed.[7] In softening plants a considerable reduction has been noted in the fluorine content of the water and alum treatment in great excess shows some removal.

TASTE AND ODOR CONTROL

CAUSES OF ODORS AND TASTES.—The most common cause of tastes and odors in water, either from a surface source or a water which has been held in an open reservoir, comes from the decomposition of dead micro-organisms. The term micro-organism includes a large variety of living creatures but the water man calls them all "algae." The various kinds of algae produce different tastes and odors in the water when they decay. The theory is that on decaying the organisms produce certain soluble oils that may or may not cause odors and tastes. Quite often these organic materials, inoffensive in themselves, will combine with chlorine to cause a disagreeable combination taste and odor. Chapter XII gives more information concerning troublesome algae and methods of controlling them. This procedure may prevent the odors and tastes. Here it is appropriate to discuss the removal of tastes and odors already in the water.

In industrial regions, troublesome phenols sometimes are discharged into streams to cause tastes in water supplies derived from them. Creosoting plants and coke plants are offenders in this respect. Such industries as gas plants, oil refineries, chemical plants, sugar plants, and tanneries produce wastes giving chemical tastes, and often times odors, in river supplies. A special problem in Texas is the waste from oil wells entering streams and reservoirs. In some instances there is a disposition on the part of industries to treat their individual wastes before discharging them into water courses. This acceptance of responsibility is to be encouraged by state and city health authorities. Removal of tastes and odors from water supplies has been a difficult problem to the water plant operator. Elimination of the trouble may, in many instances, be far more effective than attempting to remove them at the water purification plant.

The adoption of the following method of regular and systematic sampling and testing of the water in the treatment plant has been found to be helpful in measuring, recording, and controlling taste conditions.*

SAMPLING.—Samples should be taken as often as experience indicates that a change is likely to occur in the raw water. It is also possible to make this interval agree with the length of time that it takes for the water to travel through the sedimentation basins. As an average figure we will, therefore, recommend that samples be drawn regularly every 4 hours from the following points for testing: (1) raw water; (2) settled water; (3) filtered water; (4) tap water.

The sampling bottles used for this purpose should be of the wide-mouthed type, with ground glass stoppers. They should be carefully sterilized and rinsed with odor-free water immediately before sampling. It is important that the sample be taken at such a place that it will be truly representative of the quality of water it is supposed to represent. For example, in taking the settled-water sample, care should be taken to obtain a sample in exactly the same condition as it will be when it flows upon the filters. Sampling at points where eddy currents affect the flow should be avoided. The bottle should be completely filled. Samples are not taken from a tap in a line until about a gallon of water has been wasted. After collecting the samples, keep them in a cool place away from light before testing, just as is done in collecting samples for bacterial tests. Allow the floc to settle out of the settled water sample thoroughly before testing.

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* The author is greatly indebted to John P. Harris, Chicago, Ill., for the material on testing for odors and tastes. It has been taken, almost verbatim, from a paper "Control of Tastes and Odors," written by Mr. Harris.

THE THRESHOLD TEST.—Test the samples with the least taste and odor first; thus, test the tap water first, filtered water second, settled water third, and raw water last. When it is desired to keep a close check on (1) the concentration of the tastes and odors entering the plant, and (2) the extent to which they are being removed, the threshold test is used. It is applied as follows:

Apparatus and reagents.—(1) six 300-ml. Erlenmeyer flasks (Pyrex) preferably glass-stoppered. Clean, and then rinse with odor-free water before using.

(2) Supply of odor-free water. This may be prepared by treating about 2 gallons of tap water with about 500 parts per million of activated carbon, shake and allow to stand for at least 15 minutes; add 10 parts per million of alum, allow to stand for 10 minutes. Then filter through a piece of sterile cotton placed in a funnel, discarding the first portion until the filtrate comes through clear and with no odor from the cotton. Then collect the remainder for use in the threshold test.

When tests are to be run the following day, carbon can be added to a 2-gallon bottle of tap water in the evening, mixed well, allowed to stand 15 minutes, dosed with 10 parts per million of alum, and then left to stand overnight before filtering. This allows the carbon to settle out and permits a great saving in filtering time.

Another method is to boil well water or spring water, that is reasonably free of odor, until about 10 per cent of the original volume has been evaporated.

(3) A thermometer covering temperature of 65 degrees C. (149 degrees F.).

(4) Graduated cylinder of 100-ml. capacity.

Procedure.—Procure samples of the water from the filter effluent and also a sample of the raw water as it enters the plant. Any other point in the plant may also be sampled as desired for the odor test.

Place 100 ml. of the odor-free water previously prepared in one of the clean Erlenmeyer flasks.

Place 10 ml. of one of the samples of water to be tested in the 100-ml. graduated cylinder and make up to the 100-ml. mark with odor-free water. Transfer this to a clean 500-ml. Erlenmeyer flask.

Warm each of the two flasks just prepared to 65 degrees C. (149 degrees F.), cover, shake, uncover, and inhale the steam from each of them in succession, starting with the odor-free sample, to determine the difference in odor.

If there is a difference, that is, there is a noticeable odor in the flask containing some of the water being evaluated, repeat, adding only 5 ml. of the sample being tested to the graduate. Then make up as before to the 100-ml. mark with odor-free water, transfer to a clean flask, warm to 65 degrees C. and compare with the sample of odor-free water at the same temperature.

Then, depending on whether this dilution gives an odor or not, use less or more of the sample being treated until that point is reached where the odor is just discernible when compared with the odor-free blank.

The reciprocal of the dilution is the *threshold* value of the water. For example, if the threshold point is reached when 10 ml. of water is diluted to 100, the threshold value would be 100/10 or 10. Similarly, if 5 ml. of water is diluted to 100, the threshold value would be 100/5 or 20.

After using this test for a few days, the chemist can run tests on raw water and filtered water in about 10 minutes and get an accurate picture of just how much of the odor in the raw water is being removed by the process. Then too, he will know when the dosage of activated carbon or other taste-removal agent should be reduced or increased because of changes in the raw water. After some practice, he will be able to tell how much carbon should be added to produce water that will not cause customer complaints.

This test should be carefully followed through in making the routine plant tests, as it has been carefully prepared and is known to give uniform results when closely followed. Deviation from the details laid down may greatly impair the accuracy of the findings.

Of great importance is elimination of all extraneous odors from the plant laboratory where the determinations are made. The operator should, of course, carefully refrain from smoking or from taking odorous foods or beverages prior to the time of making the tests, and should eliminate any odors of soap, etc., from the laboratory and hands at the time of testing.

Day-to-day running of these tests will produce great skill, efficiency and sensitivity in the operating analyst. It will also make it possible to run a large number of analyses within a comparatively short time.

VALUE OF THE TEST.—Under normal operating conditions in the plant, and without some sudden change occurring, the operator will know from the intensity of pollution as shown by the threshold number which he assigns to the raw water, how much powdered activated carbon it will be necessary to add to the water in order to bring the threshold of the finished water down to a point where it will not cause consumer complaint.

At Springfield, Ill., Hammond, Ind., Highland Park, Ill., and Wilmette, Ill., a threshold odor of three is taken as a standard. (This is determined with open-mouth Erlenmeyer flasks.)

So long as the threshold number three is not exceeded the regular small dose of activated carbon sufficient to stabilize and brighten the water is considered satisfactory and no change is made. Just as soon, however, as a threshold of three is exceeded in the filtered water, the dose of activated carbon is increased to bring it down below three or, if a sudden increase in pollution raises the threshold of the raw water quite high, the carbon dose is stepped up before the increase becomes apparent in the filtered water.

In one plant a dose of 1 part per million of activated carbon is rated as sufficient to reduce the threshold number by about four threshold points. At another plant the threshold reduction is calculated at about three for each part per million of powdered activated carbon added; at other plants the ratio may differ considerably from either of these two.

This divergence is quite likely to be due to the different taste-and-odor-producing pollution in the raw water at these two plants, for no two polluting substances are removed by activated carbon on exactly the same ratio, and, even in the same water plant, a change in the polluting bodies to be adsorbed and removed by the carbon may immediately change any ratio which may have been previously set up.

That is the reason why, in making threshold determinations, the operator should not only assign a numerical value to the odor but should identify it definitely. So, in addition to the regular routine threshold determination, the operating analyst should be prepared to run tests in order definitely to determine in advance the amount of activated carbon to be applied to make sure that tastes and odors will not break through into the finished water. His tests should also indicate any change in the character of the tastes and odors in the raw water, in addition to any sudden change in the intensity of the pollution.

METHODS OF TASTE AND ODOR CONTROL.—In the treatment for taste and odor no definite directions can be given. The operator must find his own best method by use of the tools that are known to be available. Aeration of all types helps to remove odors. The spray type is probably most efficient. Aeration, however, only reduces the odor to some extent and cannot be depended upon to remove the trouble completely. The available materials that can be used as aids in taste and odor removal and prevention include: chlorine, applied by the methods known as superchlorination, prechlorination, or as a combination of chlorine and ammonia (chloramine); coagulation, with one or more of the coagulants already discussed; and powdered activated carbon. All the methods have their uses and very often no single one will do the complete job. Which can be used to best advantage must be determined by the operator to suit the particular water he has to treat.

Superchlorination has not been widely used, although Toronto, Canada, has employed it for years. By superchlorination is meant the addition of more chlorine than is necessary merely to kill or hinder the growth of bacteria or to be absorbed by organic matter. From 1 to 5 parts per million is used depending upon whether it is applied in treated, filtered, settled, or raw water. If the raw and settled waters are highly turbid, it is advisable to superchlorinate the filtered water. The amount necessary in normal filtered water would not be more than 1 or 2 parts per million. Whenever superchlorination is applied, there should be available a means of removing the excess chlorine 2 hours after the addition of chlorine. This means the use of a "dechlor" or a chemical which combines with the excess chlorine to produce an inactive compound. Common "dechlors" are sulfur dioxide gas or bisulfite of soda. In case of the use of sulfur dioxide the ratio of the required amount to chlorine is about 1 to 1. Superchlorination, followed by dechlorination, is expensive but quite satisfactory in removing the tastes and odors due to most types of algae. For removal of tastes and odors due to industrial wastes this method is not recommended.

Prechlorination or addition of chlorine before filtration is quite common. This procedure sterilizes the water before filtration and frequently will affect small amounts of organic matter in such a way as to prevent taste and odor. Importance of prechlorination as a safety measure cannot be over-estimated. The long contact of the chlorine with the water may give practical sterilization. Then additional chlorine can be added after filtration as a precaution against the possibility of bacteria remaining in filter effluent. The chlorine in the coagulation basin helps to prevent the growth of algae on the walls and in the filter sand. Quite often it is an advantage to use ammonia along with chlorine at this point, thus reducing the required amount of chlorine and making it more effective in killing bacteria and algae. Usually 1 pound of ammonia to 4 pounds of chlorine is a good ratio. Individual waters may, however, need some variation from this to produce best results.

Ammonia for this use is available in several forms: as a gas free from water; as a solution in water; or in the form of such common salts as ammonium sulfate (chemical soil fertilizer) and ammonium chloride. Where consumption of ammonia runs into tons per year, the use of ammonium sulfate may be advisable, since it works as well as the other forms of ammonia and is less expensive. Ammonium sulfate must be fed as a solution. While it is on the market as a crystal, dry-feeding is unsatisfactory because of rapid lumping of the material in storage and in the machine. If it is practicable to mix it with dry coagulant and thus proportion it with the coagulant satisfactory dry-feeding is possible.

Postchlorination, or the addition of chlorine after filtration should be considered only for the purpose of finishing the work of sterilization not accomplished before the filters. Some plants, however, have successfully chlorinated only after the filters, properly sterilizing and also preventing combination tastes. Unless, however, there is provision for very long contact before the water enters the mains and some means to apply a dechlor this practice is not recommended for odor and taste removal.

Ammonia is often used with the postchlorination to prevent formation of chlorinous tastes and to extend the time of sterilization for greater or less periods from the time of chlorination. Addition of the ammonia just before the chlorine is common practice, although at times greater efficiency seems to result from following with the ammonia shortly afterward.

Chlorine, although useful in removing odors and tastes in some cases, is not a cure-all. It may itself, as already indicated, be an offender by causing a combination taste with organic matter or give its own characteristic taste and odor.

Coagulation is principally useful in taste and odor removal by reducing the organic load upon the other agencies of taste and odor removal. Particularly does it add to the efficiency of chlorine. The primary aim of coagulation, the removal of turbidity, makes it limited in usefulness for other purposes.

Since 1932 activated carbon has become a very popular agent for taste and odor removal. While carbon also cannot be thought of as a cure-all for taste troubles, yet it bids fair to accomplish the major part of taste and odor removal. Activated carbon accomplishes results by adsorbing the small amounts of organic impurities which cause tastes and odors. It will also remove hydrogen sulfide, excess chlorine, and chlorinous tastes. It is usually applied in finely powdered form either as the water enters the coagulation basin or just ahead of the filter. When added in the coagulation basin it will settle with the floc and adsorb products of decomposition in the sludge. This has the advantage of reducing odors and tastes which originate there, but the short period of contact with the water itself lowers the efficiency of the carbon in reducing tastes and odors already in the water. Dosing just ahead of the filter allows the carbon to be caught in the sand where it removes the troublesome matters as the water passes through. When the filter is washed the carbon is removed.

The dose that may be used is limited by the amount the filters can take without having the loss of head unduly increased. Doses up to 50 pounds per million gallons should not cause trouble. Doses of less than 5 to 10 pounds per million gallons do not usually produce results worth the cost. Doses from 10 to 50 pounds per million gallons, if properly applied, will materially improve a taste condition. A small dry-feeding machine with a water eductor is excellent for this service. It is important that the carbon be thoroughly wet before it gets to the water.

Prechlorination followed by carbon makes a good combination treatment to handle the heavier concentrations of taste and odor. The two used together will accomplish considerably more than either one alone.

Operators should exercise care in selection of a carbon. Carbons vary greatly in quality, with differences that are not visible to the eye. When considering the purchase of a carbon supply, consult some of the large users who have checked the various brands offered for sale.

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CHAPTER X

THE WATER PURIFICATION PLANT

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PLAIN AND PRESEDIMENTATION.—When water is impounded or is passed through a settling device of some sort the velocity is slowed down practically to zero, and as a consequence much of the suspended matter or turbidity settles to the bottom. Ponds and lakes, both natural and artificial, may be considered as plain settling devices under ordinary conditions. They remove tremendous quantities of mud and silt, and in time they themselves become filled up unless provision is made for removing the deposited material. Lake Austin at Austin, Texas, furnishes a striking example of such a condition.

Presedimentation basins find their greatest application in connection with slow-sand filter plants and are not as a rule incorporated in the design of the modern rapid-sand filter plant, except in special cases. Thus in the treatment of very turbid river waters such as those of the Mississippi, Missouri, Arkansas, and Brazos, or other streams in the southwestern states, presedimentation offers distinct advantages.

The advantages claimed for presedimentation are: (1) the removal of the bulk of the turbidity and reducing the load on the coagulation basins; (2) it gives a water lower in turbidity and more uniform in character for subsequent treatment; (3) it reduces the cost of the coagulating chemicals that must be used later.

In a series of tests conducted by the Dorr Company at Jefferson City, Missouri, on Missouri River water, it was shown possible to reduce the turbidity from 80 to 95 per cent, with a detention period of 3 hours. This reduction is possible because the turbidity consists of rather coarse, quickly settling particles and is present in very large amounts. Preliminary sedimentation is, therefore, considered of value only where the suspended matter is fairly coarse and settles rapidly. It is obvious that not much advantage would result from preliminary sedimentation when applied to water of low turbidity such as would come from impounded supply.

There are various types of presedimentation basins and they differ in their details. They may be simple earthen basins or they may be constructed of concrete or other materials, and of various shapes. Some are equipped with mechanical devices for removing the deposited mud or sludge. It is claimed that in tanks equipped for mechanical sludge removal that the sludge volume is 30 per cent less than with direct settling. The detention period may vary from a few hours to several days, although in the mechanically cleaned type the detention period is kept as low as is consistent with good practice. It is important that inlets and outlets be properly designed and that baffles be provided, if necessary, to prevent short circuiting. Artificially constructed basins usually vary in depth from 8 to 20 feet.

Preliminary sedimentation is provided at Atlanta, Ga., Kansas City, Kans., Cincinnati, Ohio, Kansas City, Mo., Louisville, Ky., New Orleans, La., Omaha, Neb., Philadelphia, Pa., Richmond, Va., St. Louis, Mo., St. Paul, Minn., Tulsa, Okla., Washington, D. C., Wilmington, Del., and other places, having a very high raw water turbidity. In Texas, Waco was an outstanding example while the turbid Brazos River was the source of supply. The largest installation in the world is now under construction near Yuma, Arizona. There 8 billion gallons of Colorado River water will be treated daily and turned into the All-American Canal to irrigate the Imperial Valley of California. For this purpose 72 Dorr clarifiers, 125 feet in diameter will be employed, removing about 70,000 tons of mud and silt daily.

AERATION.—Aeration, as the word itself implies, is a process whereby the water is brought into intimate contact with air for accomplishing one or more of the following purposes: (1) removing or reducing taste and odors; (2) removing gases such as carbon dioxide and hydrogen sulfide; (3) for oxidizing iron and manganese compounds occurring in water; (4) for introducing oxygen into the water.

Aeration should not be considered as a bacteria-removing process although some incidental reductions have been reported. In taste and odor removal by aeration the gases are swept out mechanically. Very little chemical oxidation takes place, and its success is probably due to the breaking up of the fragile micro-organisms with subsequent ''sweeping out'' of the liberated material.

The types of aeration devices used in water treatment include the following:

(*a*) Spray nozzles operated by either gravity or pumping pressure.

(*b*) Step or cascade aerators where the water discharges over steps or riffles.

(*c*) Tray and splash pan aerators, where the water drips through perforated trays that are usually filled with some rough ballast.

(*d*) Air injectors.

(*e*) Diffused air applied through perforated pipes or porous plates.

(*f*) Paddle wheels and other mechanical devices.

Spray nozzles probably give the best aeration, but unless they can be operated by gravity pressure, they have the disadvantage of increasing the pumping head quite materially. Fort Worth uses this type of aeration, the nozzles being operated under a head 7 to 10 feet at the base and discharging 150 gallons per minute at the higher head.

Step or cascade aerators are relatively inexpensive to operate as the additional head required is little or none. They usually provide three or four steps, each 1 to 1.5 feet high, over which the water passes in a thin sheet with more or less splashing. The water rises through one or more vertical pipes to the top step. Steps are not as a rule as efficient as spray or fountain aerators. Dallas uses the riser pipe and cascade type of aerator.

Tray aeration with subsequent filtration through coke beds finds its greatest use in iron and manganese removal plants. Waco, Texas uses plain tray aeration without coke or other contact media and for taste and odor reduction only.

Among the injector types may be mentioned a patented device which combines aeration and mixing in one operation. An installation of this type may be seen at Denison, Texas.

Diffused-air and paddle-wheel aerators are generally ''after-developments,'' added to the plant by the operator when he encounters difficulty. There are many and very ingenious arrangements of home-made aerators.

No one type of aeration is to be recommended over all other types, as local conditions are the governing factors. Each type is to be studied carefully before its adaptation to local conditions. In general, it may be said that the spray or fountain type is the best for removal of taste- and odor-producing gases.

CHEMICAL FEEDING AND DOSAGE.—Chemical feeding is probably the most important phase of all water treatment. Improper feeding of chemicals can only result in disastrous endings, so far as plant results are concerned. If an operator feeds too much chemical, in addition to obtaining improperly treated water, he is wasting substantial sums of money. If he does not add enough, he immediately encounters difficulty with his filters—the sand becomes clogged, the filter runs shorten, wash-water percentage increases, and turbid water, with excessive amounts of bacteria, may get into the distribution system. Neither over- nor under-dosing is to be tolerated, but in the interests of safety a little too much chemical is better than not enough.

There are a great many kinds of chemical feeding devices but they can all be classified as either solution- or dry-feed types. In the solution-feed apparatus the dissolved chemicals are fed into the water, after being measured by some form of device for measuring liquids, such as an orifice under constant head, a weir, a Venturi or other meter, a proportional flow meter or similar arrangement. A few chemicals absorb moisture to form lumps and therefore are not suitable for dry feeding. Ammonium sulfate, for example, is best applied by solution feed.

Most operators prefer the dry-feed machines. Solution feeds have the disadvantages of requiring large quantities of water for dissolving the chemicals, the orifices become clogged up, pipe lines corrode or become incrusted, the solutions must be made of different strength from time to time, and with certain kinds of chemicals the solutions must be agitated or stirred continuously to prevent settling.

In the dry-feed type the chemicals are added either by direct-weighing machines, which are provided with conveyor arrangements, or by volumetric additions made by mechanically or electrically actuated mechanisms. Dry-feed machines may be of various types, such as the screw conveyor, drum-wheel dragging past an orifice, revolving disk or table with cut-off blade, and the oscillating hopper type. A very recent design is the electric vibrating type, in which a trough or spout is set under an over-head hopper at a slight angle and the spout is vibrated by an electro-magnetic device. All of the machines mentioned can be set to deliver the chemicals accurately within wide ranges.

Certain precautions must be taken in operating dry-feed machines. It is important to keep the chemicals free from moisture to prevent packing or bridging in the storage hoppers, and the "get away" must be designed to avoid splashing the receiving water against the measuring or moving parts of the machine. It is important also to use a dust-proof type of feeder, to prevent the dusty material from blowing all over the plant and causing unsightly buildings, both inside and out. This is especially true when feeding finely divided chemicals, such as activated carbon.

When caustic or quicklime is used it is necessary to "slake" it before use. Slaking consists of adding water to the lime to form the hydrate. The process should be carried out at as high a temperature as possible. A number of plants employ hot water for slaking purposes. The process is carried out in iron or concrete tanks provided with agitators or rakes to insure complete contact between the lime and water. The milk of lime is fed to the water from the slaking tank at the same rate as the weighed lime is added to the tank.

In unloading or handling large quantities of chemicals in bulk, such as lime particularly, many ingenious mechanical handling devices are used, such as power shovels, and conveyor systems using pneumatic methods, screws or belts.

Chemical feed machines, both the solution- and dry-feed types, can be arranged to feed in proportion to the incoming raw water flow, but it should be needless to say that every operator should calibrate his measuring devices so that he can determine instantly at what rate he is applying chemicals.

Extra parts to replace those most likely to wear out or break down should be kept on hand to avoid long shut downs. In addition, all plants should have duplicate or reserve machines, since it is highly important that the chemical treatment be continuous. The importance of continuous and proper dosage cannot be stressed too strongly.

MIXING AND FLOCCULATION.—After the chemicals have been added to the water it is necessary to mix them thoroughly to insure contact with every particle of the water to be treated. It apparently requires very little stirring or mixing actually to distribute the chemicals throughout the water, but it does require careful mixing to produce the proper floc necessary to settle and filter effectively. It is also essential once the floc is formed that it is not broken up again.

The two primary requirements are proper velocity of the water, and sufficient reaction time. Rather turbulent mixing can be done at the instant of adding the chemicals, provided it is later followed by a slower velocity, but the reverse should not be permitted, since violent disturbances will break up the floc, once it has been formed.

There are a number of kinds of mixing tanks, but they may be broadly divided into two classes: (1) baffled, or hydraulic mixing basins; (2) mechanical mixing basins.

The earlier plants employed the first-named type, which are essentially rectangular tanks, with various arrangements of baffle walls. These were of two general types—the "end-around" baffle and the "over-and-under" baffle. In the "end-around" type, baffles are built alternately from the sides either across the narrow or across the wide dimension of the tank. Short baffles give more loss of head than the long baffles. In the "over-and-under" type, as the name indicates, the water flowed over the top of a baffle wall and then under a baffle and so on. The principle in both cases was to cause the water to "turn over on itself." It should be remembered that adequate mixing depends not on how far the water travels but on how often it is turned over. Table XII gives design data on mixing tanks.

Mechanical mixers are of comparatively recent appearance in the field. This type usually includes a paddle-wheel arrangement driven by suitable machinery so as to give a stirring effect. Mechanical mixers provide great flexibility since they are usually built in relatively small units, thus permitting different numbers to be used, and also, as a rule, means are provided for varying the speed of the mixing blades or paddles. Table XII gives data on tanks of this type.

In some plants mixing is accomplished by introducing the chemicals into a conduit ahead of the coagulation basin and allowing the velocity of the moving water to do the necessary mixing. In still other cases the chemicals are introduced into the suction end of

TABLE XII.—VELOCITY AND MIXING TIMES OF MIXING TANKS

	Average	Maximum	Minimum	Median
End-around tanks (ave. of 15)				
Mixing time—minutes	26	60	2	30
Velocity—feet per minute	69	190	20	60
Length of travel—feet	1871	5056	150	1600
Loss of head—feet	1.5	3.3	0.4	1.2
Over-and-under tanks (ave. of 16)				
Mixing time—minutes	21	60	0.17	10
Velocity—feet per minute	63	360	4.1	43
Length of travel—feet	1003	5280	49.5	425
Loss of head—feet	1.1	3.3	0.1	1.0
Mechanical mixing tanks (ave. of 7)				
Mixing time—minutes	21	40	10	17
Velocity—feet per minute	82	120	48	60

the pumps which force the water to the plant. There is also the patented injector device referred to in aeration.

A recent development in mixing is the combination of "flash" mixing and "flocculators." In the "flash" mixer, the chemicals are introduced directly below the throat of a high speed impeller that rapidly diffuses the chemicals throughout the incoming raw water and also lifts the water a short distance. The mixing time is just a few minutes. The water then travels to what are known as "flocculators," which are paddles revolving around a horizontal shaft directly across the path of the incoming water. These paddles operate at peripheral speeds of about 0.6 to 1.8 feet per second and give the water a rolling motion which tends to form large flocs. The contact time ranges from 30 to 90 minutes. In some plants, poor preliminary mixing has been improved by the installation of secondary flocculators at the inlet to the coagulation basins.

COAGULATION BASINS.—After the water and chemicals have been mixed, and the floc has formed, the floc and its entrained suspended matter are allowed to settle out in coagulation basins, more commonly but erroneously called settling basins. These basins are usually built of concrete and are of various sizes and different detention periods. They may be open or closed, depending on climatic conditions. They are usually constructed in two or more units, so that one basin can be cut out of service for cleaning. In recent years the tendency has been toward the use of coagulation basins with mechanical continuous sludge removal devices. There are a number of different types of mechanically cleaned basins in use. Table XIII shows the detention periods used and other design data.

TABLE XIII.—CHARACTERISTICS OF COAGULATION BASINS
(Average of 53 Plants)

	Average	Maximum	Minimum	Median
Detention time—hours	7.5	62.5	1.0	4.0
Velocity—feet per minute	2.1	12.0	0.4	1.5
Depth—feet	16.5	43.0	6.5	16.0

The basic requirements are that basins should have quiescent flow, sufficient sludge capacity to provide storage between cleanings, proper baffles to prevent short circuiting, provide even distribution, and prevent disturbing velocities. There should be inlet and outlet control valves, and a slope to the bottom leading to a drain of ample size, in order to facilitate easy and rapid cleaning. Conduits or pipes leading from the mixing basin to the coagulation basin should be of such design to keep turbulence at a minimum and to avoid breaking up floc that has already been formed. This is a quite common fault that reduces the efficiency of many plants.

Inlets to coagulation basins should be constructed to avoid scouring of the deposited sludge. This is done in a number of ways, such as providing multiple inlets spaced properly at intervals across the end of the tank, by use of hanging baffles, or by perforated baffles. The ''take off'' from the basin is usually a long weir extending across the basin so as to take off the top water.

Coagulation basins should be kept free from floating material such as dead fish, leaves and other debris by daily skimming. They should also be cleaned of sludge at proper intervals if they are not of the continuously cleaned type. Open basins are very favorable for algal growths, and it is a good plan to paint the side walls to a depth of about 6 or 8 feet with a strong solution of copper sulfate each time a basin is cleaned. This will keep down the growth for a time, but when it appears later control should be applied by dragging a small sack of copper sulfate attached to a string or pole along the surfaces that show these growths.

RAPID-SAND OR MECHANICAL FILTERS.—Since this Manual is primarily intended for Texas water plant operators, and there are no slow-sand filters in Texas, no further reference will be made to that type.

The rapid-sand filter, as the name implies, filters water at a very much higher rate than the slow-sand filter. Under normal conditions this is 125 million gallons per acre daily or 2 gallons per square foot of sand surface per minute. In a few instances under special conditions plants have been designed for 160 million gallons per acre per day.

Rapid-sand filters are constructed in units depending upon the required capacity of the plant. The lower limit for size seems to be about 500,000 gallons per day for very small plants, while the upper limit appears to be from 3 to 4 million gallons per day, with a few units as large as 6 million gallons per day in use at very large plants.

A plant is seldom or never constructed with the entire plant capacity represented by a single filter unit. Two or more units are essential so that one can be taken out of service for repairs or cleaning when necessary and to give the flexibility in output necessary to meet varying water consumption rates.

The essential parts of a filter are:

(1) The tank or filter box itself.
(2) Inlet and distribution system.
(3) Effluent and underdrain system.
(4) The filtering medium of gravel and sand.
(5) Rate controllers.
(6) Operating tables.
(7) Loss-of-head gauges.

TANK OR FILTER BOX.—This usually consists of a square or rectangular concrete box with vertical walls. The shape has nothing to do with the efficiency of filtration, but much consideration must be given to the design of the distribution and under-drain systems. In the earlier plants, circular wooden or steel "tubs" were used but in modern plants the construction is universally of reinforced concrete. In some plants the inside surfaces of the filters are purposely made rough by "guniting" to discourage the passage of water without filtration between the walls and the sand.

INLET AND DISTRIBUTION SYSTEMS.—It is important to have the settled-water main and the individual inlet lines to the filters of ample size, so that velocities are kept low enough to avoid breaking up the remaining floc, since this is needed to form a mat over the sand surface and aid in filtration. Velocities in inlet pipes are usually kept at 2 to 3 feet per second.

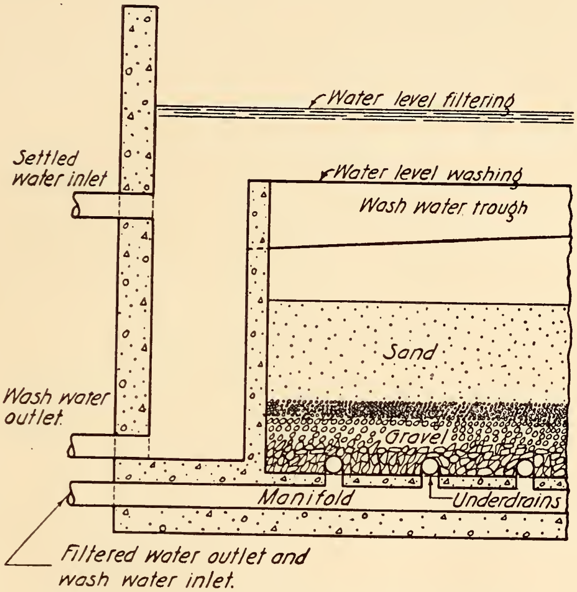
Water level filtering
Settled water inlet
Water level washing
Wash water trough
Sand
Wash water outlet
Gravel
Manifold
Underdrains
Filtered water outlet and wash water inlet.

FIG. 17. Section through a rapid-sand filter.

The inlet of a filter unit discharges into the filter box in such a fashion that the gutter system of wash water troughs helps to distribute the settled water evenly over the surface of the filter. The main purpose of the wash-water troughs, however, is to collect and carry away the spent wash water. In the earlier plants these troughs were constructed of metal, but in recent designs they are made of concrete. It is essential that they be spaced properly to distribute the incoming water equally without causing any currents and that in each filter the tops of the troughs are at the same elevation, so as to collect and carry away the wash water. They must also be at such a distance above the sand surface that no sand will be carried away when washing at maximum rates. A good "rule of thumb" is to make the top of the troughs the same distance above the top of the sand as the maximum rate of vertical rise per minute of the wash water. Since the usual rate of applying wash water to filters is at the rate of a vertical rise of 24 inches per minute the edges or lips of the troughs are generally 24 inches above the sand.

EFFLUENT OR UNDERDRAIN SYSTEM.—The effluent or underdrain system requires careful design. It must be liberal enough in size to carry away the filtered water, and it must be designed so that when used as a wash-water distribution system it will give ample and uniform delivery of wash water without the formation of jets or high velocity areas. In some cases the bottoms of the filters are simply flat surfaces with the distribution system laid on top, while in other cases special bottoms are used. The common practice is to call the entire system a "bottom" or "strainer" system. Quite a number of different designs are in use. The more common may be classified as follows in order of predominance:

(*a*) A central manifold with perforated pipe laterals.
(*b*) A central manifold with pipe laterals and brass strainers.
(*c*) Perforated brass plates over ridge-and-valley bottoms.
(*d*) Perforated false-bottom slab with strainers.
(e) Wooden-slat grid.
(*f*) Wheeler bottom.
(*g*) Wagner bottom.
(*h*) Half-round cast-iron pipe slightly raised above the floor with a slot orifice between the edge of the pipe and the floor.

GRAVEL AND SAND.—In the bottom of each filter, to support the filtering sand proper and to break up the incoming wash water to prevent channeling, is placed a bed of graded gravel. The depth of this bed is usually 16 to 18 inches and consists of three to five layers of different sizes, according to the ideas of the designing engineer. The largest size is on the bottom and the smallest on top. Table XIV gives the depths and sizes of gravel as used in practice. Intermediate layers between the largest and smallest sizes of gravel are arranged so that the size of grain in each layer is about twice the size of the layer above.

The filtering sand is placed directly on top of the gravel. In some of the older plants bronze screens were placed between the gravel and sand but this practice has been abandoned. The depth of the sand bed varies, the average being about 26 to 28 inches.

The sand must be carefully selected as to effective size and uniformity coefficient. Too fine a sand will clog up too rapidly, while with a coarse sand the water will not filter properly, consequently there are certain limits of sizes that are used in practice. In designating the properties of filter sand the terms "effective size" and "uniformity coefficient" are used.

TABLE XIV.—GRAVEL AND SAND USED IN RAPID-SAND FILTER UNITS

	Average	Maximum	Minimum	Median
Gravel (65 plants)				
Total depth—inches	16.8	34.0	8.0	17.0
Size of largest grain—inches	2.0	3.0	0.75	
Size of smallest grain—inches	0.12	0.25	30 mesh	
Sand (62 plants)				
Total depth—inches	27.7	37.0	18.0	
Effective size—millimeters	0.436	0.60	0.33	
Uniformity coefficient	1.50	2.00	1.20	

By "effective size" is meant that size of sand grain such that 90 per cent is coarser than the stated size, and 10 per cent is finer than that size. "Uniformity coefficient" is a term used to express the relationship or uniformity of the sand sizes making up the lot of sand. It is defined as the ratio between that size of sand grain than which 60 per cent is finer and 40 per cent is coarser, to the "effective size." The methods of determining this effective size and uniformity coefficient are given in Chapter XVI. Table XIV shows sand bed thicknesses, effective sizes and uniformity coefficients as used in practice.

The selection of the proper sand is quite important and depends on the type of treatment the water has had previous to filtration. The tendency in recent years has been toward a slightly larger sand than formerly, especially in those plants which soften the water. Other things being equal, rounded grains are preferred to angular grains. In any case the sand should be free from dirt, flat grains, or any particles over 1 mm. in diameter. Specifications generally also call for a silica sand so pure that 95 per cent remains insoluble in 10 per cent hydrochloric acid. Satisfactory filter sand is obtainable from Texarkana, Goliad, and the Texas

Silica Sand Company of Houston, which has its sand pits at Corrigan.

Some years ago a few plants were constructed using crushed anthracite coal instead of sand. The old Turtle Creek plant at Dallas was of this type. At the present time an effort is again being made to introduce anthracite coal for this purpose under the trade name of "Anthrafilt."

RATE CONTROLLERS.—A rate controller is a device installed in the effluent line from a filter unit whose purpose it is to maintain automatically a constant rate of filtration. Such control is necessary to overcome the increased loss of head caused by the progressive clogging of the sand. There are a number of different kinds of controllers, but in all cases they perform the same service, namely opening or closing a throttling valve or device automatically so as to maintain a constant predetermined rate of filtration. Fluctuations in rate of filtration are highly undesirable as they may materially affect the quality of the effluent.

OPERATING TABLES.—Operating tables are mounted in front of the filter and on them are placed the levers by which various valves necessary to operate the filter are opened and closed. They also carry indicating devices which tell the degree of opening or closing of the valves, the loss of head, and the rate of flow. In some cases tables also have a sampling device which allows the operator constantly to observe the characteristics of the water being turned out by the filter. It will be seen that the operating table and its parts are almost essential to intelligent plant operation.

The tables are constructed of slate, marble, art stone, or other material. The metal parts may be finished in nickel or chrome plating or other finish to harmonize with the tables. Filter tables and their mountings are the "show places" of the plant. In very small plants the tables may be omitted where the valves are operated by hand rather than hydraulically or electrically as in the larger plants.

LOSS-OF-HEAD GAUGES.—Loss-of-head gauges are for the purpose of indicating to the plant operator the condition of the filter bed. They measure and indicate the loss of head or pressure the water suffers in passing through the filter bed. In the simplest form the gauge consists of two vertical pipes, one connected to the filter itself at a short distance above the sand and the other connected to the effluent line outside the filter. The difference in the height of water in the two pipes is the loss of head. Different ingenious devices are used to indicate or record this loss of head on dials or charts. The loss of head is very small immediately after washing the filter but it increases as the sand accumulates floc and mud removed from the water. When the loss of head, as shown by the gauge, has reached the limit considered to be safe or desirable by the operator the unit is washed.

FILTER WASHING.—When water is filtered through a rapid-sand filter, the floc and suspended matter remaining in the coagulated and settled water form a skin or blanket on and just below the top of the sand, and this blanket plays a large part in the removing of the bacteria. The mat gradually increases in thickness and offers more and more resistance to the flow of water, until a point is reached where the filter stops up entirely or the mat cracks and allows the water to rush or break through. When this occurs the water streaming rapidly through the restricted sections of the filter is not properly treated. Before such a dangerous condition is reached the filter should be washed. The question arises—how does the operator know when to wash? The loss-of-head gauges are the indicators which tell him. Just how much loss of head can be built up depends on the relative height of water on the filters and in the filtered-water storage reservoir. Generally filters are washed when the loss of head reaches about 8 feet. Usually the initial loss of head on starting a washed filter is less than 1 foot. If more than this, it indicates a dirty or improperly washed bed. The rate of washing varies, depending on the design of the filter.

In the early days of rapid-sand filters wash-water velocities of 12 to 15 inches vertical rise per minute were commonly employed. In many instances this was augmented by "air washing," or forcing air through small perforated pipes located just above the strainer system. In later designs the air-wash system is omitted and higher water velocities are used, 24 to 36 inches upward rise per minute. Present day practice includes variations in upward rise from 12 inches to 38 inches per minute with the average about 24 inches.

The time of wash-water application varies from 3 to 10 minutes. The amount of wash water used in a well operated plant should not greatly exceed from 2.0 to 2.5 per cent of all water filtered.

The wash water, as a rule, is supplied by gravity from a small auxiliary elevated tank generally holding from two to three times the water necessary to wash one filter. This tank is filled with filtered and chlorinated water, otherwise the filters would become seeded with bacteria and their effectiveness would be lost. In some cases filters are washed by direct pump pressure taking water from the clear well. It is more economical to fill the elevated storage tank with a separate pump connected to the clear well, than to use water from the high-service lines. The height of the bottom of the wash water tank above the top of the sand in the filters is usually from 30 to 35 feet.

Improper filter washing usually results in the formation of "mud balls." When this occurs the only remedy is to break up the balls with rakes or other tools, and adopt a higher rate of washing. A recent innovation has been the use of "surface wash" to supplement the wash water rising from the underdrains. It has proved to be useful in preventing mud balls. The surface wash water is applied by means of 1-inch vertical pipes on 2-foot centers terminating 4 inches above the sand. Each pipe has a brass cap on the end with four holes ¼ inch in diameter bored so that three water jets are directed about 38 degrees below the horizontal while the fourth hole is directed vertically downward. Water is applied through the surface wash pipes at 10 to 15 pounds per square inch pressure at about 5 gallons per square foot per minute; while at the same time back washing is going on at an upward flow of 7 to 15 gallons per minute or about 12 to 24 inches vertical rise per minute.

Filters should be kept free from floating debris by skimming when necessary. Algal growth on the troughs and walls should be kept at a minimum by hosing and by application of copper sulfate.

At Fort Worth, it has been found that painting the walls and troughs with a whitewash made of lime, presents a better appearance than the bare concrete surfaces. This permits the algae to grow a little faster, but they are very much easier to dislodge with a squirt hose.

OPERATION.—Since filtration is the last step in the clarification of water it is very important to maintain the filters in proper condition. The chemical treatment must be properly done since it determines the efficiency of the coagulation and settling and this in turn determines the efficiency of the filter. Regardless of the changes in the raw water, the preliminary treatment must be regulated in such a manner that the water going to the filters is as near constant in quality as possible. Water applied to the filters should not have a turbidity of much more than 10 parts per million. Greater than this may result in ''smoky'' water in the effluent, or it may build up loss of head too rapidly and result in excessive use of wash water.

Periodic bacterial tests should be made on the effluent from each individual filter to see if it is functioning properly. For sampling a bib cock is installed in the effluent line. If excessive bacteria are found it may indicate a polluted underdrain system. This can be corrected by applying a dose of heavily chlorinated water to the inlet and allowing it to filter through slowly and then wasting the water to the sewer, or still better, tapping the wash-water line and adding chlorine to the wash water as it enters the filter.

In plants filtering lime-softened water the sand grains in the filter become incrusted with calcium carbonate and in time masses of sand will cement together, offering much resistance to the flow of water, and presenting difficulty in washing. The increased size of the sand grains may also affect the efficiency of the filter. This can easily be prevented by adding an acid to the incoming water in just sufficient amount to neutralize all the normal carbonate alkalinity. The usual acid employed is carbonic acid, or carbon dioxide gas, as it is commonly called.

In the operation of a filter there are a number of precautions that should be observed. Valves should be opened and closed slowly, especially hydraulic valves. They should never be allowed to ''slam'' since this may cause sticking. If a valve operates too quickly or an operator refuses to slow it down, a metal orifice plate of proper size may be inserted in a union in the water supply line to the cylinder. Stems should be kept well packed so that no leakage takes place. Wherever possible hydraulic cylinders should be installed vertically. The four-way cocks for cotrolling the hydraulic valves should be lubricated whenever necessary by greasing with tallow. Tallow is about the only lubricant that will ''stay put'' on these cocks. Water pressure should not be kept on a hydraulic-valve cylinder except when operating the valve.

Needless to say all instruments and indicating devices should be kept in an operating condition. Rate controllers and loss-of-head gauges should be checked at frequent intervals for their accuracy. Brass trimmings should be kept polished. A coat of clear lacquer applied after polishing will protect the polish for a long time.

FILTERED-WATER STORAGE RESERVOIRS.—After filtration the filtered water passes to the clear well or filtered-water reservoir. These clear wells are of many shapes and sizes. The capacity is usually governed by the National Board of Fire Underwriters' requirements and local conditions. Concrete construction is almost universally used. The clear well should, of course, be water tight to prevent entrance of pollution and loss of filtered water. Good practice requires that clear wells be covered over to prevent entrance of dust, insects, and other foreign matter carried by winds. By covering and keeping the clear well dark, growths of algae are prevented. Proper air vents, protected against entrance of contamination, are necessary. Inspection-manholes should be water tight and fool-proof. Baffle walls are usually provided to give circulation and prevent stagnant area. Inlets and outlets should be of ample size and so constructed that all the water in the clear well is made available to the pumps. If more than one clear well is necessary, they should be connected in series so as to give continuous circulation, and keep the "dead end" effect to a minimum.

Water-proofing of clear well walls, while highly desirable, should be used with caution. Nothing should be used which might cause a taste or odor to form. Piping to and from the clear wells should be so arranged that, if necessary, units may be taken out of service for repairs.

Cleaning should never be necessary if properly filtered water is delivered to the reservoir, unless, of course, the reservoir is of open construction. All reservoirs should be equipped with water-depth recording gauges so that the operator knows at all times how much water he has in storage and also how fast he is gaining or losing it.

KEEPING RECORDS.—It is of utmost importance to keep adequate and accurate records at all plants. Such records should include:

The daily air temperature.
The daily raw water temperature.
The daily rainfall.
The daily stage (gauge height) of the water supply whether stream or reservoir.
The total amount of water filtered.
The amount of wash water used.
The number of filter units in service.

The number of hours the filters are in service and the total hours of filtering.
The length of the filter runs between washings, average, maximum, and minimum.
The length of time wash water was applied.
The amount of wash water used and percentage of filtered water.
The upward rate of wash in inches rise per minute.
The initial loss of head when the filter is first placed in service.
The final loss of head just before the filter is washed.
The total pounds of each kind of chemical used and the rate of dosage in parts per million or grains per gallon.
Daily averages of the chemical and bacteriological tests.

The number and kind of the chemical and bacteriological tests that should be made will in a great measure be determined by the type of plant and degree of treatment. Usually included are the alkalinity tests, turbidity, pH, residual chlorine, hardness (if softening is practiced), the presumptive and confirmed *B. coli* tests, and the total bacterial count.

As a rule each operator develops a system of his own in keeping records. Regardless of the system of record keeping, the main point stressed here is the *necessity* for keeping systematic records. By proper record keeping variations in operation can be detected quickly and the necessary corrections can be made.

THE PRESSURE FILTER.—Pressure filters are, in effect, rapid-sand filters enclosed in cylindrical steel tanks, with the water passing through them under pressure. They are obtainable from manufacturers in sizes from 16 inches to 60 inches in diameter for the upright types. The larger sizes are cylinders with their axes horizontal and these can be obtained in sizes 7 and 8 feet in diameter and up to 25 feet long. The filtering sand and the gravel used in them approximate in specifications those of the gravity filters. Arrangements of piping and valves allow reversal of flow and backwashing of the sand. Loss-of-head gauges are necessary and automatic rate controllers are highly desirable. Observation glasses in the piping permit a view of the filtered water and also of the waste wash water. Since efficiency of the filter depends upon a small amount of floc in the applied water, provision is necessary for adding chemicals in small amounts. In the fluent line, therefore, there is a bypass line leading to a "pot" through which a small stream of water passes, dissolves some chemical and returns to the influent pipe. Large installations will have a battery of filters and these will be connected to single headers, thus permitting backwashing of one unit by the effluent of the others, otherwise some special provision is necessary for washing.

Pressure filters, although efficient in clarifying water, are considered to be uncertain in bacterial removal. Consequently state health departments generally object to their installation where it is necessary to make an unsafe water safe. Their principal fields of usefulness are: removal of precipitated iron from ground waters; removal of precipitated material in softened ground waters; and treatment of recirculated swimming pool waters. They are frequently used in the treatment of water for industrial purposes.

Pressure filters have the advantages of requiring very little space, and they can be used without the necessity of an extra pumping lift. When used for the purposes mentioned above they are frequently operated at a rate of 3 gallons per square foot per minute, or 50 per cent greater than the standard rapid-sand filter rate.

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CHAPTER XI

DISINFECTION OF WATER

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Disinfection is used in water supply practice to kill the germs of disease that may be in the water. The term sterilization is sometimes used in this connection but sterilization, strictly speaking, is the destruction of all life. The disinfectants used in water do not kill all life, although they can be depended upon to kill disease organisms. Boiling, however, will sterilize water but it is not a practical procedure for municipal water supplies. A secondary use of disinfection is to retard or prohibit the growth of non-disease producing organisms, such as various forms of algae, in order to eliminate and prevent taste, and improve the operation of filter plants.

Water may be disinfected by the following agents and methods:

Chlorination.
Boiling.
Distillation.
Ultra-Violet ray.
Ozonization.
Oligodynamic silver.
Iodine.

Chlorine and Its Properties.—Chlorine is a heavy greenish-yellow gas that is very active in combining with other substances. When applied to water it will oxidize organic matter and destroy bacteria. In order to obtain the bactericidal action it is important to be certain that the chlorine demand of the other organic matter is satisfied. Accordingly, a simple test is applied to the water to determine whether there is a residual of free or unused chlorine after a contact period of about 10 minutes. The test used is the orthotolidin test, described in Chapter XVI, and if a residual of free chlorine is found by it, there can be certainty that dangerous bacteria will have been killed. The chlorine is somewhat selective in its action in that it is more deadly to *B. coli* than to some other types of bacteria, and even more deadly to disease organisms than to *B. coli.* Hence if, after chlorination, a water shows complete or practically complete absence of *B. coli* it can be considered as safe.

Various chlorine compounds are available for water disinfection. When added to water their chlorine is released and it acts in the same way as gaseous chlorine and can be checked by the orthotolidin test.

CHLORINATION.—Liquid chlorine is the most used and, under usual conditions, is the most practical and the most economical means of safe-guarding a water supply from water-borne diseases. Chlorine, although a gas, becomes a liquid when compressed. If the pressure is released it again becomes a gas. Liquid chlorine may be purchased in steel cylinders containing 100 pounds, 150 pounds, or 2000 pounds of chlorine. The price of liquid chlorine depends principally upon the amount purchased. Cylinders in less than carload lots may cost about 10.5 cents per pound in Texas. In carload lots in cylinders, chlorine may be purchased for approximately 9 cents per pound. Large users of chlorine buy it in the 2000-pound cylinders at approximately 4 cents per pound, but in order to buy cylinders of this size, it is necessary that the city use more than 30,000 pounds per year. A deposit of $20.00 is usually required on a chlorine cylinder, and a rental charge of 50 cents per month is made if the cylinder is retained after ninety days (1936).

Liquid chlorine is used in three different ways in the water works field. These methods or ways of application are known as postchlorination, prechlorination, and superchlorination. They are used according to the effects desired upon the water. A fourth method of application consists of combining the chlorine with ammonia and then prechlorinating or postchlorinating.

Postchlorination consists of applying the chlorine to the filtered water just before it is pumped to the distribution system. This practice is followed when disinfection is required, or as a factor of safety to elminate all possibility of disease-producing germs in the water. Usually 3 to 4 pounds of chlorine per million gallons are sufficient to disinfect a filtered or clear water. The amount necessary depends on the amount of organic matter present. The amount of chlorine applied, however, should be regulated so as to obtain residual chlorine in the water as shown by the orthotolidin test.

Prechlorination is so called because the chlorine is always applied to the raw or incoming water to the plant. Sometimes chlorine is applied before aeration and sometimes after aeration, depending upon the local conditions. About 8 pounds per million gallons is the average amount used for prechlorination. Frequently a residual is held through the coagulation-sedimentation basin to the filter. Prechlorination is used for prohibiting or retarding algal growths in the aerator, settling basins, and filters, with the added beneficial effect of prevention of tastes, better physical condition of the filter beds, and decreased wash water consumption. If the raw water is very highly polluted prechlorination also has the advantage of reducing the bacterial load upon the filter.

Superchlorination, which is just coming into use in Texas, as the term implies, is the application of large amounts of chlorine to oxidize organic tastes or odors. This subject is discussed in Chapter IX.

Chloramine is a combination of ammonia and chlorine. The ammonia is usually added just before the chlorine in the ratio of 1 pound of ammonia to 4 pounds of chlorine. Several advantages may be obtained by using chloramine. High residuals may be held without danger of chlorine taste. The formation of combination tastes of chlorine with organic matter may be prevented. The killing effect of the chlorine may be retained for a long period in the distribution system, thereby providing safety against contamination which may enter there. Either prechlorination or postchlorination may be practiced with chloramine. The orthotolidin test may be applied with chloramine in the same manner as with chlorine.

DOSAGE.—Chlorine dosages are usually expressed in parts per million, one part per million being equivalent to 8.34 pounds of chlorine per million gallons of water. When disinfection is required the chlorine should, if possible, be applied in the suction pipe of the pump or pumps supplying water to the distribution system, because by so doing it is possible to apply chlorine at a fixed or known rate with the attendant mixing action of the pump. It is always important that the *rate of flow of chlorine* be set with the *rate of flow of water* in gallons per minute or per day, instead of in proportion to the total consumption of water per day.

A required dose of chlorine may be computed as follows: It is assumed that a plant pumps 1,250,000 gallons per day and it is desired to dose it with chlorine at the rate of 0.3 part per million. The water is pumped in 12 hours. The operator must calculate the chlorinator setting, which is usually expressed in pounds per 24 hours. In making the computation it must be remembered that a gallon of water weighs 8.34 pounds. The general relationship or formula will be

$$\frac{G \times 8.34 \times 24 \times D}{1{,}000{,}000 \times H} = R.$$

This may be shortened to

$$\frac{G \times 0.0002 \times D}{H} = R,$$

in which G is the number of gallons actually pumped per day; D is the required dosage in parts per million; H is the number of hours pumped per day; R is the chlorinator setting in pounds per 24 hours.

Substituting the values of the example in the above formula the chlorinator setting or rate of application of the chlorine will be 6.25 pounds per 24 hours.

USE AND CARE OF EQUIPMENT.—When liquid chlorine is withdrawn from the cylinder it expands into a gas and, because the pressure in the cylinder varies with the temperature, it is necessary in applying chlorine to water to use chlorine control apparatus. The function of the control apparatus is to reduce the variable cylinder pressure to a constant pressure and then to apply the chlorine gas at a constant and measurable rate in proportion to the flow of water. The chlorine control equipment is called a chlorinator.

There are two types of chlorinators, the direct type, which applies chlorine directly as a gas to the body or flow of water to be disinfected, and the solution type, which mixes, within the chlorinator, the chlorine gas with a small amount of water, and applies the chlorine-water solution to the water be sterilized. Chlorinators may be further divided into pressure type and vacuum type chlorinators. The pressure type uses a mechanical diaphragm spring-actuated type of pressure-reducing valve to maintain a constant pressure of chlorine gas across some type of orifice. Direct-type chlorinators are always of the pressure type. Solution-feed chlorinators are of both pressure and vacuum types. The vacuum-type chlorinator utilizes the vacuum created by passing a flow of water through an injector to act as a counter balance or a reducing valve against the cylinder pressure, and since the chlorine is metered and withdrawn from the cylinder under a vacuum, this type of chlorinator is highly efficient.

The chlorinator should be installed as near the point of application as possible. Should there be no existing building available or convenient, it will be necessary to construct one at or near the point of application. A structure of wood or other suitable material, having a floor area of about 8 feet by 10 feet is desirable. The building should be provided with good light and the construction must be such as to permit it to be kept warm and dry. It is best not to locate the building directly over an open well or water channel because of the dampness. Provision must be made to heat the building during cold or damp weather. In those cases where the apparatus will not have constant attendance, the capacity of the heating equipment should be such that it will not fail between visits of the operator. The chlorinating equipment and heating equipment should be so arranged that there will be no more heat on the chlorine cylinders than on the control apparatus. In other words, the temperature of the discharge piping from the chlorine cylinders and also of the chlorine control apparatus should always be at a higher temperature than the chlorine cylinders themselves. This is necessary in order to prevent the chlorine reaching the apparatus as a liquid rather than as a gas. To secure this, install the equipment so that the rays of the sun do not shine directly upon the chlorine cylinders. Care should also be taken that the chlorine cylinders receive less heat from radiators, etc., than does the control apparatus. If necessary, an insulating shield should be placed around the chlorine cylinders so as to deflect the heat from them. During cold weather it is recommended that the room be kept at a temperature between 60 and 70 degrees F. and certainly not below 50 degrees.

All unpainted metal parts of the chlorinator should be coated with vaseline, preferably laid on with a brush, to prevent possible external corrosion. There should be no odor of chlorine at the apparatus, except when a connection is broken for making changes. All connections should be tested each day for signs of chlorine leaks, for no leaks of any kind should be permitted. Green deposits or color on the metal parts of the equipment indicate the presence of free chlorine. Test for the leaks with strong ammonia. This is done by holding an open bottle of ammonia water (ammonium hydroxide) beneath the joint or pipe it is desired to test. Appearance of a white "smoke" indicates a leak. Every leak must be stopped as soon as discovered. All openings in the apparatus should be plugged or closed up whenever any connection is broken even for a short time. This will prevent dampness getting into the apparatus and causing trouble. Deposits will form much faster in presence of moisture. Every precaution should be taken to prevent water getting back into the chlorine gas line or gas control parts of the apparatus. The importance of keeping moisture out of the metal parts is stressed because chlorine reacts very quickly with metals in the presence of moisture, while the action on dry metals is extremely slow. Black iron pipe can be used for chlorine lines for a long time if kept perfectly dry.

Care should be taken not to damage the heads of screws or bolts. This requires use of the proper size tool when removing screws or bolts. Since these are not often removed, any bolt or screw will freeze slightly, and if the head is deformed great difficulty and delay will result. It is important that no water be used when cleaning any part of the apparatus, except glass parts. When it becomes necessary to clean out deposits in any part of the apparatus carbon tetrachloride (Carbona), chloroform, or wood alcohol are most effective. Grain or denatured alcohol, ether, gasoline, or petroleum distillates should not be used. A plentiful supply of gaskets will be needed to keep the connections in tight condition without undue straining of the unions or fittings. Chlorine valves should never be forced. If the valve does not close tightly when using the fingers there is probably something wrong with the valve. Using force will only result in straining the inside stem, stripping threads, or otherwise injuring the valve. A knowledge of the construction of the valves reduces the difficulty in keeping them in good condition. Dixon's Graphitoleo No. 692 used on all hard rubber threads before assembling prevents the parts from freezing together. Mechanical tools may cause injury if used for tightening up threaded rubber parts into other threaded rubber parts. Hand tightness is all that is required.

Although not necessary, a platform scale is very convenient for use in connection with the chlorine containers. The weight of the container is stamped on each cylinder and it is only necessary to substract this weight from the total weight as indicated by the scale to tell at any instant how much chlorine there is in the container. By taking periodic readings, the operator is enabled to check the amount of gas as used each day against the amount as indicated or required by the flow of water.

When connecting the chlorine cylinders, remove the cap from the chlorine cylinder. Under the cap will be found a valve and, at the side of the valve, a cap covering the outlet. Remove this cap carefully. Note that all cylinder valves are provided with fusible plugs below the outlet and particular care must be taken not to remove or otherwise tamper with this plug. It is considered good practice with low capacity equipment to take the cylinder out into the open air and blow off a small amount of chlorine to clear any deposit that may have collected in the valve. If not removed this might tend to clog the apparatus. Place the cylinder or cylinders on the platform scale and attach the auxiliary cylinder valves. These valves are available in both union and yoke type, whichever is preferred. In either case insert one of the special lead gaskets furnished with the equipment in the connection. Furthermore, to insure a tight joint, make sure that the surfaces against which the gasket seats are smooth and clean. Attach the flexible connections from the auxiliary cylinder valves to the manifold, using the special fibre gasket furnished with the equipment.

SAFETY PRECAUTIONS.—Contrary to public opinion, chlorine is not a deadly gas, but has a stifling and suffocating effect, with an irritation of the lung surfaces, and producing an effect similar to a common cold. The following precautions and measures should be followed in case of chlorine gas escaping:

(1) Refrain from coughing. Coughing in an atmosphere where chlorine is present is the primary cause of all reported casualties. The avoidance of coughing enables one to pass freely through heavily chlorinated atmospheres without difficulty.

(2) Keep mouth closed.

(3) Avoid deep breathing.

(4) Keep the head high. Chlorine seeks the lowest possible level.

The following first-aid measures are necessary in cases of inhalation of chlorine:

(1) Promptly remove the affected person to the open air and away from all chlorine; place him flat on his back and treat as explained below. He should be instructed to resist as much as possible the impulse to cough.

(2) Call a physician immediately. While there may not be any serious effect from exposure to chlorine, a physician should always be called.

(3) If the patient is not unconscious, give *one* of the following immediately.

(*a*) One-half teaspoonful of essence of peppermint in hot water; or

(*b*) A moderate stimulant (black coffee). This will relieve the tendency to cough and sooth the inflamed membranes, allowing the passage of air and promoting the action of the respiratory organs.

(4) If the patient is unconscious and not breathing, use the "prone-pressure" method of artificial respiration.

The following anti-spasmodic mixture for treatment of persons exposed to chlorine fumes has also been found helpful. One teaspoonful is given every half hour until relieved.

Water	80	ounces
Sugar	2½	"
Ti. Lavender Compound	2	"
Sp. Ammonia Aromatic	3	"
Ess. of Peppermint	20	"
Sp. of Chloroform	3	"

A set of operating instructions for chlorination apparatus, together with directions for treatment of gassed persons, should be placed in or near the chlorinator room and personnel should be required to be familiar with the instructions. The room itself should be well ventilated. A gas mask should also be on hand to permit quick repairs in case of a severe leak or break. The Burrell gas mask, with Type GMC canister, made by the Mine Safety Appliance Company, Pittsburgh, Pa., is especially valuable for this purpose.

CALCIUM HYPOCHLORITE AND SODIUM HYPOCHLORITE.—Next in importance to liquid chlorine as a means of disinfecting water are the chlorine compounds, calcium hypochlorite and sodium hypochlorite.

Calcium hypochlorite is available commercially in two forms:

(1) Ordinary chloride of lime, containing 25 to 35 per cent available chlorine.

(2) High test hypochlorite, containing 60 to 70 per cent available chlorine, sold under various trade names, such as ''Perchloron'' or ''HTH.''

Ordinary chloride of lime is available in cans containing net weights of 1 pound, 10 pounds, or in drums containing 100 pounds or 500 pounds. HTH and Perchloron are available in cans containing 4 pounds net, or in drums containing 100 pounds.

Calcium hypochlorite solution is prepared by mixing a specified number of pounds of chloride of lime, HTH or Perchloron with a specified number of gallons of water in order to make up a solution of the desired strength. Calcium hypochlorite is best applied as a solution by means of a constant-head flow box and variable orifice, or some displacement type of mechanism. There are three or four types of equipment on the market today for applying calcium hypochlorite.

Sodium hypochlorite is similar to calcium hypochlorite except that caustic soda or soda ash is added to the calcium hypochlorite solution. Sodium hypochlorite is applied and measured in the same manner as calcium hypochlorite.

There are disadvantages to the use of the hypochlorites. Commercial chloride of lime is very unstable and loses strength rapidly. It is also disagreeable and difficult to handle in large quantities. HTH and Perchloron are relatively stable but much more expensive than chloride of lime, and like chloride of lime, are both annoying and cumbersome to handle in the large quantities necessary in treating large volumes of water. The outstanding usefulness of the hypochlorites is as an emergency disinfecting method, and also for very small supplies.

BOILING.—Boiling is the simplest and surest method of sterilization to use when the water is questionable and other means are not available. Boiling, however, as a means of sterilization is limited to individual or household use and it is not practical for large quantities of water.

Boiling should be done for 10 to 15 minutes and thereafter care must be taken to keep the water covered so that no additional contamination may enter. In emergencies, such as a failure of the water supply, or an interruption in chlorination, boiling should be done, since it requires only a kettle and a fire and it can be done by anyone. Water works authorities should, if any emergency, as a flood or other catastrophe, has contaminated the water, give immediate notice to householders to boil the water before using it for drinking or cooking purposes.

DISTILLATION.—In distillation, water is boiled and converted into steam which is then condensed by some sort of cooling device. Distillation is seldom used in municipal supplies. Its greatest application is on shipboard where the water is salty and cannot be used in its original form. Sterilization by distillation is a secondary action, since distillation is primarily used to obtain water free from mineral salts. It is comparatively an expensive process.

ULTRA-VIOLET RAYS.—Ultra-violet rays are sometimes used to disinfect water. The rays are produced by passing electric current through mercury vapor inclosed in a quartz tube and which is so placed that the water passes by it several times in relatively thin sheets. Ultra-violet rays will nearly or completely sterilize water, if the water is free from turbidity and color, and it is passed through the apparatus at the proper rate. It has the advantage of giving no taste or odor to the water. The equipment is expensive and operating charges are considerably higher than when using chlorine. It does not have any residual disinfecting effect upon the water. It has been used extensively at swimming pools, but the fact that there is no residual action available to kill disease organisms as given off by bathers detracts from its usefulness for this purpose.

OZONIZATION.—In this process the ozone or ozonized air is brought into contact with the water by suitable means, and the disease bacteria are destroyed. Ozone is oxygen containing three atoms to the molecule instead of two as in the ordinary atmospheric oxygen. The third atom is only loosely bound to the molecule and easily unites with organic matter, thus giving both an oxidizing and disinfecting action. Ozone is produced by passing a silent electric discharge through air or oxygen. The ozonized air is then applied to the water. It has never gained wide-spread use in United States, but has been used to some extent in France, Russia, and Germany. The equipment is quite complicated and operation costs are high. The amounts used are usually from 3,000 to 5,000 grams of ozone per million gallons of water, which is equivalent to 6.5 to 11.25 pounds. The water to be treated should be free from turbidity and color to produce the best results.

OLIGO-DYNAMIC SILVER.—In this method of disinfection, also known as the katadyn process, water is brought into contact with finely divided or colloidal silver. The apparatus used consists of silver electrodes around which the water passes, the colloidal silver being given off by electrolytic action. In the finely divided state certain metals, and particularly silver, will kill bacteria. In a recent test of the katadyn process conducted by Dr. Frank E. Hale, Director of Laboratories, New York City Water Supply, he states:

> "While laboratory results indicate that the *B. coli* group may be controlled in the absence of ammonia, both the laboratory experiments and swimming pool results indicate that the 37 degree C. count of bacteria is not affected, and among these bacteria may be disease germs affecting the eye, ear, nose or throat. The required time for sterilization is too long, at least two hours.
>
> "The economy of the process is also questioned when compared with chlorine. The recommended silver dose for a pool is from 0.15 to 0.20 parts per million. As silver costs several dollars per pound and chlorine a few cents per pound, the comparison is evident.
>
> "The most serious drawback is the possibility of an outbreak of argyrosis. This malady causes the skin to become permanently dark as the result of a silver deposit. Once it develops, there is no known cure at present.
>
> "Silver acts as an algicide in the same manner as copper."

IODINE.—Iodine is recommended by many state and city health departments to prevent the so-called "vacation typhoid" attributed to the use of unsafe water by motorists, campers, picknickers, and vacationists in general. Ordinary tincture of iodine, obtainable in any drug store, is used. Two or three drops will be sufficient to disinfect a quart of water. After dosing, the water should be thoroughly stirred and allowed to stand 20 minutes before using.

CHAPTER XII

ALGAE, AND CONTROL METHODS ADAPTABLE TO TEXAS WATERS

BY CHESTER COHEN

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Algae are simple forms of plant life. Most types require warm temperatures, and sunlight, in addition to suitable food, for their development. The algae spores, or resistant forms of the organisms, are transported through the air by wind, by animals, or by physical means in much the same way as bacteria, yeast or other plant seeds. The mature plants are usually to be found in uncovered reservoirs such as lakes, tanks, ponds, and swimming pools. Due to their wide prevalence and ability to develop in natural waters, and especially in the favorable temperatures and conditions as to sunlight that exist in the southern states, special care must be exercised in their control lest they develop in troublesome numbers.

EFFECTS OF ALGAE.—The most important effect of algae in public water supplies is the taste and odor which they may cause. The living algae secrete and excrete aromatic substances which impart various tastes and odors to the water, the commoner being described as earthy, moldy, woody, and fishy. Dead algae may impart the same odors considerably intensified and, if present in large numbers, may, by decomposition of their bodies, cause putrescent odors.

Algae growths are responsible for other troubles: for discoloration of the water in which they are developing; clogging of filter beds of both water and sewage plants by filling the interstices or pores of the filtering material and reducing the rate of filtration; clogging of water condenser tubes and interference with heat transfer; reduction of flow rates in water mains and sometimes serious clogging. Some of the lower forms of algae are able to grow in the absence of sunlight and will develop in the alum and iron solution feed lines leading to the coagulation basin, to cause clogging of the pipes and preventing the chemicals from reaching the water. The growth of algae in a water supply may also provide a favorable medium of bacterial growth and thereby cause the supply to appear less favorable from a laboratory standpoint than would otherwise be the case. In swimming pools they are especially objectionable because of the cloudiness or green color imparted to the water and the slimy growths on the sides and bottom of the pool.

CLASSIFICATION OF ALGAE.—Algae are simple forms of plant life, found mostly in water, and growing as single cells, filaments, chains, or masses of cells. A great many of them contain green coloring matter but some also have blue-green, brown, red, or yellow color. The green, blue-green, and brown algae are the most common types to be found in fresh waters, as ponds, lakes, reservoirs and streams, while the red types are found mostly in ocean waters. Since there are many thousands of varieties of algae, it is obviously an enormous undertaking to try to become acquainted with more than a few of the most prominent groups.

The actual counting and identification of the organisms is quite a problem for anyone not familiar with the proper methods. Where it is desired to know what type of alga is causing trouble it is best to send a sample of the water to the State Health Department.

A determination of algae in water is concerned not only with the species but also with the number present. This calls for collection of a representative sample of the water and then a concentration of the organisms so that they can be found, identified, and counted under the microscope. The various methods of concentration, and the technique of counting are explained in Part V, "Standard Methods of Water Analysis" of the American Public Health Association, 8th Edition. Some of the more important groups of algae will be discussed briefly.

Diatoms.—The diatoms comprise a group which are chiefly one-celled plants, the cell material being enclosed in a beautifully marked cell wall of tough siliceous substance. Diatoms which lived ages ago and whose siliceous parts settled in lake beds formed the diatomaceous earth which is used commercially as an ingredient in silver polish, tooth paste, etc. In addition to their green coloring matter (chlorophyll), diatoms also have a brown coloring matter which is easily distinguished under the microscope. They reproduce usually by cell division. Common examples are: Asterionella, which is often found in lakes and reservoirs. It is star-shaped. The dead organisms cause aromatic, fishy or geranium odors.

Synedra, also frequently found in reservoirs, imparts an earthy odor to the water.

Cyanophyceae.—These often form a frothy scum or dark green "water bloom" in quiet waters. They are of common occurrence in summer and may grow in polluted waters or those containing much organic matter. They have a blue-green color and are either free-floating or in gelatinous masses or strata, single cells, filaments, or chains. They do not necessarily have a definite cell nucleus. A common species is anabaena, which produces a grassy odor and occasionally an especially vile pigpen odor.

Chlorophyceae.—This highly important group, the green algae, is characterized by the presence of chlorophyll. They comprise a wide range of organisms from single cells to multicellular and flagellate forms. They reproduce both asexually and sexually. The group includes many thousand forms, from the stringy filaments so frequently found attached to walls and sides of tanks and open channels, to single free-floating forms. Examples are: Spirogyra, which forms green stringy masses near the water surface and under moderate magnification shows beautiful spirals of pyrenoids. It causes a "vegetable" odor. Cladophora, conferva, hydrodictyon (water net), zygnema, are all filamentous and give a "vegetable" odor on death and decomposition. Endorina and volvox, both of which give a fishy odor, are sometimes classed among the chlorophyceae but more properly, perhaps, belong among the flagellate protozoa.

Protozoan flagellates.—These constitute the lowest form of animal life, and are on the borderline between plants and animals, possessing some of the characteristics of both. This group is distinguished by the presence of cilia or threadlike appendages which are used to assist them in moving about in the water. Examples are: Dinobryon, which produces an aromatic or fishy odor, and synura, which may impart cucumber, muskmelon, fishy or bitter taste or odor. Endorina and volvox properly belong in this group.

Schizomycetes.—These are bacteria closely allied to the algae. Examples are the beggiatoa or "sulfur bacteria," which cause a decayed, hydrogen-sulfide odor, and the crenothrix, or "iron bacteria," which also cause an offensive decayed odor.

CONTROL METHODS.—There are two well known methods of preventing algae growth, the choice of which depends upon whether the growth is occurring in small storage basins or large impounding reservoirs. Small basins and tanks can be easily covered, thus excluding sunlight and thereby checking the growth of the organisms. Where large impounding reservoirs are used, it is imprac-

TABLE XV.—DOSAGES OF COPPER SULFATE AND CHLORINE USED IN CONTROLLING ALGAE

Organisms	Copper Sulfate *		Chlorine	
	Parts per Million	Pounds per Million Gallons	Parts per Million	Pounds per Million Gallons
Diatomaceae				
Asterionella	0.10	0.8	0.5–1.0	4.2– 8.3
Melosira	0.30	2.5	2.0	16.7
Synedra	1.00	8.3		
Navicula	0.07	0.6	1.0	8.3
Chlorophyceae				
Conferva	1.00	8.3		
Scenedesmus	0.30	2.5		
Spirogyra	0.20	1.7	0.7–1.5	5.8–12.5
Ulothrix	0.20	1.7		
Volvox	0.25	2.1	0.3–1.0	2.5– 8.3
Zygnema	0.70	5.8		
Coelastrum	0.30	2.5		
Cyanophyceae				
Anabaena	0.10	0.8	0.5–1.0	4.2– 8.3
Clathrocystis	0.10	0.8	0.5–1.0	4.2– 8.3
Oscillaria	0.20	1.7	1.1	9.2
Aphanizomenon	0.15	1.2	0.5–1.0	4.2– 8.3
Protozoa				
Euglena	0.50	4.2		
Uroglena	0.05	0.4	0.3–1.0	2.5– 8.3
Peridinium	2.00	16.6		
Chlamydomonas	0.50	4.2		
Dinobryon	0.30	2.5	0.3–1.0	2.5– 8.3
Synura	0.10	0.8	0.3–1.0	2.5– 8.3
Schizomycetes				
Beggiatoa	5.00	41.5		
Crenothrix	0.30	2.5	0.5	4.2

* Dosages of copper from "Microscopy of Drinking Water" by M. C. Whipple.

ticable to attempt covering. In this case, a chemical may be added to the water to eliminate or control the plant growth. The usual chemical agent employed is copper sulfate or ''blue stone,'' although later experiments have indicated that the use of chlorine may also serve effectively. The dose to be used of either agent depends upon: (1) the individual organisms to be destroyed; (2) the amount of dissolved and suspended organic matter in the water; (3) the characteristics of the water, such as chemical content, turbidity, color, and temperature; (4) the retention period to be allowed the supply after treatment or allowable period of time for keeping the unit out of service; (5) the use which is to be made of the treated water.

There are other possible methods of algae control, but they exist more or less as theoretical possibilities. There might be mentioned the elimination of the chemical compounds, particularly carbon dioxide, in the water which serve as algae food; or, the application of coagulants which would drag the algae down to the bottom of the reservoir, after which the sediment could be flushed out without interfering with the continuous operation of the system; or, again, the growths could be controlled through adjustment of hydrogen ion concentration.

The amounts of copper sulfate and chlorine required by the commoner types of algae are shown in Table XV. It will be noted that there is considerable variation in the killing doses. Copper sulfate is injurious to fish and under certain circumstances it may be necessary to dose lakes or reservoirs with caution to prevent heavy casualties among their fish population. Table XVI gives the maximum amounts which various species of fish can withstand without injury.

TABLE XVI.—TOLERANCE OF FISH TO COPPER SULFATE

Fish	Parts per Million	Pounds per Million Gallons (approximate)
Trout	0.14	1.2
Carp	0.30	2.5
Suckers	0.30	2.5
Catfish	0.40	3.5
Pickerel	0.40	3.5
Goldfish	0.50	4.0
Perch	0.75	6.0
Sunfish	1.20	10.0
Black Bass	2.10	17.0

There are objections to the use of chemical agents for the elimination of algae growth, all of which are worthy of consideration. 1. Chemical treatment is a temporary measure and does not provide permanent relief. 2. Under-dosages are ineffective and wasteful. 3. Over-dosages may result in (*a*) discoloration of the water, (*b*) in temporarily rendering the supply unsuitable for use due to excess contained chemicals and (*c*) in killing off fish life in a stream receiving copper-treated effluent. 4. The weight of public opinion opposes chemical treatment or ''doping'' of a drinking water supply. 5. The possible poisonous effect to the human system of copper salts. The question regarding the effect of copper salts on the human system is still debated although there is no strong evidence of injury to persons. The question as to the rate of precipitation and elimination of the copper salts in the reservoir is also disputed. 6. The possibility exists of an objectionable taste forming through combination of chlorine and dead and putrefying organic matter.

Satisfactory algae control consists of keeping the plant growth at a minimum. In other words, prevention of trouble is preferable to cure. This necessitates regular microscopical examinations and counting of the forms in order to be able to check the growth when an increase is observed. The importance of this laboratory work has never been sufficiently emphasized—it is the basis and the beginning of all successful control. The examination also permits the immediate detection of the more objectionable forms which require immediate treatment. Samples taken at different depths in the reservoir will indicate the zones of growth. It may then be necessary only to treat that volume of water in which the algae are growing. In lakes of 100 acres area, for example, this determination will save about 200 pounds of copper sulfate for each 1 foot of depth which the microscopic examination shows that it is unnecessary to treat. The example in the following article illustrates the method of computing copper sulfate dosage.

DOSAGE CALCULATION.—Assume that the microscopic analysis indicates that asterionella is the predominant organism and that it is growing to a depth of 7 feet below the surface of the reservoir, the area of which is 50 acres, or 50 × 43,560 square feet. This figure, multiplied by the depth of growth gives the volume of water to be treated which equals 50 × 43,560 × 7 or 15,246,000 cubic feet. This again multiplied by 7.5 equals 114,345,000 gallons. From the table of dosages for copper sulfate, we find that for the destruction of asterionella, 0.10 part per million or 0.83 pounds per million gallons will be required. As indicated by Whipple * this dosage must be increased or decreased by 2.5 per cent for each degree below or above 15 degrees C. Assume that the average temperature of the water in the reservoir is 17 degrees C. We will, therefore, decrease the required dosage by 5 per cent of 0.83 pounds which equals 0.04 pounds. The adjusted dose, therefore, to meet this temperature condition is 0.8 pounds minus 0.04 pounds or 0.79 pounds per million gallons. According to Whipple an increase of 2 per cent in the dosage must be made for each 10 parts per million of organic matter. Assume that the impounded water has an organic content of 10 parts per million so that the total dosage must be increased 2 per cent of 0.79 pounds which equals 0.015 pounds. This brings the adjusted dosage to 0.79 pounds plus 0.015 pounds which equals 0.805 pounds. The final correction is that the copper sulfate must be increased by 0.5 to 5 per cent for each 10 parts per million of alkalinity. Assume the alkalinity of the water to be 25 parts per million and an average increase of 0.3 per cent per 1.0 part per million of alkalinity, or 0.3 × 25 which is 7.5 per cent. This per cent of 0.805 pounds equals 0.060 pounds. The final adjusted dosage is then 0.805 pounds plus 0.60 pounds or 0.865 pounds per million gallons. We have further that an increase of 5 per cent in the amount in the total dosage would be needed if the amount of carbon dioxide in the water is low. We will not consider this factor because most of our impounded waters have a sufficient amount of carbon dioxide for the chemical action required in the copper treatment process. The final corrected dosage is, therefore, 0.865 pounds of copper sulfate per million gallons of water to be treated. We previously determined that the volume of water to be treated was 114,345,000 gallons so that the total quantity of copper sulfate required is 0.865 × 114 which equals about 95.2 pounds for the asterionella growth in this particular reservoir.

This same example applies to the use of chlorine, but in this case the dosage would have to be calculated by first determining the chlorine demand of the water to be treated and then applying enough chlorine to give the residual quantity required for the particular organism. In the copper sulfate method, we have the total quantity of copper sulfate necessary, whereas in the chlorine method

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* Whipple, M. C., "The Microscopy of Drinking Water." Fourth edition. Published by John Wiley and Sons, Inc., New York, 1927.

the dosage is based on the residual value rather than on total chlorine to be applied. This must be done because chlorine has an affinity for organic matter in the water and is more easily oxidized than is copper sulfate.

In the event that a table of required copper sulfate or chlorine dosage is not available it is well to keep in mind that an average copper sulfate dosage effective for the greater number of organisms is about 1.0 part per million or 8.3 pounds per million gallons; and for the chlorine dosage an average figure would be about 0.75 parts per million of residual chlorine. By knowing the requirements of the type of organism we wish to eliminate, we may effect considerable saving of chemicals. That is, only 0.865 pounds of copper sulfate proved sufficient in the above case, whereas, with the type of organism and other qualifying factors in the treatment unknown, we would have had to assume the average of 8.3 pounds per million gallons or ten times the amount actually needed. This saving may well be considered as offsetting the cost of microscopic equipment necessary.

APPLICATION OF COPPER SULFATE.—Copper sulfate may be applied either as a powder or in solution. Application of a solution feed could be effected by dissolving the chemical in a tank placed on a boat and spraying the solution over the surface of the water or distributing it at the different depths by means of a hose connection. Application in the powered form would be accomplished by dragging sacks of the copper sulfate through the water over such a course and at such a rate that would permit an even distribution in dissolving the chemical through the entire body of the reservoir to be treated. The problem of uniform dosing with copper sulfate is the most difficult and yet the most important point connected with reservoir control. Fish life, as shown by Table XVI, is killed by certain concentrations of copper sulfate, and overdosing of certain parts of the reservoir may kill many fish. On the other hand, if certain portions of the reservoir receive under-dosage, the algae are not affected, and then not only has the chemical been wasted, but the under-dosed portions of the reservoir will serve as seeding places to recontaminate the rest.

At Los Angeles a method has been developed by which dry crystals of copper sulfate are distributed over the surface of the water by means of a specially designed power-driven scattering disk. The very fine crystals will float on the surface until dissolved, while the coarser crystals will dissolve as they descend, thus dosing the deeper layers. The larger the crystals are the deeper is the water dosed. The method has the disadvantage that the finely divided material is apt to blow back onto the boat and on the operators, requiring them to wear goggles.

At San Francisco a stream of water is forced through an injector throat creating a suction at the constricted section. At this point a side opening admits copper sulfate crystals which are carried with the water through spray nozzles over the surface of the supply. The water for the operation is pumped from the supply itself by means of a pump in the boat.

CHLORINE TREATMENT.—The use of chlorine as an algicide possesses certain advantages over copper sulfate. They are: (1) it is more easily applied in a solution; (2) the residual gas will be largely dissipated into the air after a short time and, therefore, cannot be accused of affecting the health of the water consumer; (3) it is especially applicable in small reservoirs where chlorine is already being applied as a bactericidal agent and only a small increased dosage is required to make it serve as an algicide; (4) such small basins, where the retention period is short, do not require the dosed unit to be thrown out of service, whereas, the copper sulfate treatment may make it desirable to do so to prevent the chemical from entering the mains. As a disadvantage—where chlorine is used as an algicide, attention should be called to the possibility of over-chlorination, which would result in imparting a chlorinous taste to the water, with the possibility of causing complaints from the consumers.

HEALTH ASPECTS.—It is generally conceded that, aside from the psychological effects caused by unpleasant tastes and odors, algae do not directly concern the health of the consumer, except as they may make a water supply so unpalatable that the consumer will go to other unsafe sources for his drinking water. The symbiotic relationship between algae and bacteria, although not well understood, may, however, play a part in determining the sanitary quality of supply, as specified by our recognized standards. According to the latest U. S. Public Health Service Standards a drinking water supply should be "clear, colorless, odorless, and pleasant to taste." With the possible exception of dissolved mineral salts, sewage, and trade waste pollution, there are no agents other than algae growths more important in determining the physical characteristics of a water supply.

FUTURE CONTROL.—The conviction is growing among sanitary engineers that the most successful method of combatting algae will be finally by means of systematized biological control. For instance, in a large lake which has swampy areas adjacent to it, or which is fed by slow moving brackish streams or by streams from swampy areas, large amounts of soluble, organic food material and algae spores will be washed into the lake proper by every rain. This usually results in a tremendous rise in the algae population. The obvious remedy here is to shut off these polluting areas through the construction of low-water dams or to deepen the adjacent water bodies, or drain the swamps. Similarly, as our knowledge of algology increases, practical methods of controlling food supplies and enlisting the efforts of natural enemies and inhibiting factors may be developed that will be more effective and more economical than chemical control.

CONTROL OF AQUATIC VEGETATION.—Growths of chara, pond lilies, and other types of water weeds cannot be destroyed by ordinary dosages of copper sulfate or chlorine. The only successful method of dealing with the larger plant growths is to cut them below the water line or to drag the bottom of the reservoir in such a way as to remove or pull them out, including the stems and roots. The work of removal should be begun before the seed ripens in order to prevent a greater distribution of growth. In the early summer, or when the lake is at its lowest level, will probably be the best time to do this work.

CHAPTER XIII

WATER SOFTENING

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In this chapter it is proposed to discuss briefly the various phases of water softening, to include the present day methods by which water is softened, the advantages and disadvantages that may be found in the production and use of a softened water, and to give some information as to the costs of procuring such water. The economies possible by the use of softened water will also be pointed out.

HARD WATER AND ITS CAUSES.—Hard water is the classification ordinarily given to a water that has a high soap-consuming power, or one in which a lather cannot be produced without the use of an excessive quantity of soap. This property of hard water is caused by the dissolved chemical compounds in the water which combine with the soap. The principal hardness-causing compounds are the salts, mainly the bicarbonates and sulfates, of calcium and magnesium. The common names given these minerals are:

Magnesium sulfate	Epsom salts
Calcium sulfate	Gypsum
Magnesium bicarbonate	Solution of magnesite in water with carbon dioxide
Calcium bicarbonate	Solution of limestone in water with carbon dioxide

The chlorides and nitrates of calcium and magnesium, as well as other dissolved substances, may be present in the water to form hardness, but they are usually of secondary importance as compared with the sulfates and bicarbonates.

Formerly the hardness due to the sulfates was called permanent hardness and that due to the bicarbonates was termed temporary hardness. The terminology now in common use is non-carbonate hardness for that due to the sulfates and carbonate hardness for that due to the bicarbonates.

Water softening is the term applied to the process of removing totally, or in part, the hardness-causing chemicals. While there are several methods by which water may be softened there are only two whose cost and adaptability will permit of large-scale application. These two methods are the lime-soda process, where the calcium and magnesium are precipitated as calcium carbonate and magnesium hydroxide respectively, and the zeolite or base-exchange process, where the calcium and magnesium in the water are replaced by sodium from the zeolite.

LIME-SODA SOFTENING.—As there are many waters in which the desired amount of softening may be attained simply by removing the carbonate hardness the lime-soda method may be considered in two parts: (1) where lime alone is used to remove the carbonate hardness; (2) where soda ash (sodium carbonate) is used in conjunction with the lime to remove the non-carbonate hardness.

A water attains carbonate hardness by dissolving calcium carbonate and magnesium carbonate in the presence of carbon dioxide to form the bicarbonates of calcium and magnesium. The process of softening with lime consists essentially of removing the carbon dioxide from the soluble bicarbonates. The resulting calcium carbonate is soluble only to the extent of about 2 grains per gallon and should precipitate down to this limit; the magnesium carbonate formed when the carbon dioxide is expelled from the magnesium bicarbonate combines with an additional amount of lime to form the hydrate of magnesium. As this compound is insoluble it will also precipitate.

The following equations express the reactions involved when limestone and magnesite go into solution:

$$\overset{\text{limestone}}{CaCO_3} + \overset{\text{carbon dioxide}}{CO_2} + \overset{\text{water}}{H_2O} = \overset{\text{calcium bicarbonate hardness}}{Ca(HCO_3)_2},$$

$$\overset{\text{magnesite}}{MgCO_3} + CO_2 + H_2O = \overset{\text{magnesium bicarbonate hardness}}{Mg(HCO_3)_2}.$$

The softening process with lime may be expressed by the equations:

$$Ca(HCO_3)_2 + \overset{\text{lime}}{Ca(OH)_2} = \overset{\text{insoluble calcium carbonate}}{2\,CaCO_3} + 2\,H_2O,$$

$$Mg(HCO_3)_2 + 2\,Ca(OH)_2 = \overset{\substack{\text{insoluble}\\ \text{magnesium hydrate}}}{Mg(OH)_2} + 2\,CaCO_3 + 2\,H_2O.$$

As the sulfates of calcium and magnesium are relatively soluble in water it is to be expected that most natural waters will contain some of these minerals in solution. In cases where part or all of this non-carbonate hardness must be removed to reach the required degree of softening, soda ash (sodium carbonate) must be used in conjunction with the lime. The soda ash converts the calcium and magnesium sulfates into their respective carbonates, which permits their removal by precipitation. The chemical reactions involved in the removal of the non-carbonate hardness may be expressed by the following equations.

$$\underset{\text{gypsum}}{CaSO_4} + \underset{\text{soda ash}}{Na_2CO_3} = CaCO_3 + \underset{\text{sodium sulfate}}{Na_2SO_4},$$

$$\underset{\text{Epsom salts}}{MgSO_4} + Na_2CO_3 + Ca(OH)_2 = Mg(OH)_2 + CaCO_3 + Na_2SO_4.$$

From the relations expressed by the above equations it is possible to compute the theoretical quantity of chemical necessary to produce the desired degree of softening. To determine the approximate quantity required the following analytical data are necessary:

(1) Free carbon dioxide. For determinations see p. 218, Chapter XVI.

(2) Half-bound CO_2. This is 44 per cent of the total alkalinity as determined in the control of the lime-soda process (see below).

(3) Non-carbonate hardness. Measure 200 ml. of the water into a Pyrex glass Erlenmeyer flask, boil 10 minutes to expel free carbon dioxide, and add 25 ml. of N/10 "soda-reagent" (2 grams sodium hydroxide and 2.65 grams of anhydrous sodium carbonate and distilled water to make 1 liter). Boil to a volume of about 100 ml., rinse into a 200-ml. graduated flask with boiled, distilled water, filling the flask to a little above the graduation mark; cool and make up to exactly 200 ml. with boiled, distilled water. Filter, rejecting the first 50 ml., and titrate 50 ml. of the filtrate for excess soda-reagent, using N/50 sulfuric acid and methyl orange as an indicator. If $S =$ N/50 sulfuric acid equivalent of the soda-reagent used, and $N =$ milliliters of N/50 sulfuric acid required for the back titration, then the non-carbonate hardness in parts per million, as $CaCO_3$ equals $20(S - N)$. If S is exceeded by N non-carbonate hardness is present. See also Chapter XVI.

(4) Magnesium. Measure 100 ml. of the sample into a 200-ml. graduated Pyrex flask (volumetric) and neutralize the alkalinity with N/50 sulfuric acid. Boil gently to about 50 ml., and add 25 ml. of saturated lime water, make up to 205-ml. mark with boiling distilled water. Place on a steam bath for 15 minutes, stopper, and cool. The volume should shrink on cooling to the 200-ml. graduation on the flask. Let stand until the precipitate completely settles, draw off with a pipette 50 ml. of clear solution into a tall Nessler tube, and titrate with N/50 sulfuric acid, using phenolphthalein as in indicator. If S represents the number of milliliters of acid required to neutralize 25 ml. of lime water and N the number of milliliters of the same acid required to neutralize the excess lime water in the sample, then magnesium in parts per million equals $2.4\ (S - 4N)$.

The *lime* required, expressed as 100 pounds of $Ca(OH)_2$ per million gallons of water to be treated for removal of carbonate hardness will be the following (with amounts in the formula expressed in parts per million): (Free CO_2 + Half-bound CO_2) 0.14 + (Magnesium) 0.25.

The amounts so obtained are based upon 100 per cent $Ca(OH)_2$ or hydrated lime. Allowance must be made for impurities in the lime. The better grades of hydrated lime will contain about 90 per cent $Ca(OH)_2$. Where quicklime is used the amount required, also expressed in 100 pounds per million gallons, will be (with amounts in the formula expressed in parts per million): (Free CO_2 + Half-bound CO_2) 0.106 + (Magnesium) 0.19.

The better grades of quicklime will contain about 90 per cent of CaO.

The *soda ash* required, expressed as 100 pounds per million gallons of water treated for removal of non-carbonate hardness, will be the non-carbonate hardness as $CaCO_3$ in parts per million multiplied by 0.091.

The best grades of soda ash will contain about 99 per cent of Na_2CO_3. In actual practice slightly more than the theoretical amounts of all softening chemical are used.

APPLICATION OF CHEMICALS.—Either hydrated lime or quicklime may be used in the softening process. Small plants will find it more advantageous to use hydrated lime, whereas larger plants using a large quantity will find it more economical to use quicklime. The hydrated lime is easier to store and does not require slaking equipment. Quicklime, although more difficult to store and requiring slaking equipment, is cheaper per ton of available calcium oxide.

The lime may be introduced into the water as a milk of lime (lime slurry), as a saturated lime solution, or through dry-feed machines. The most common practice at the present time is that of feeding milk of lime, and it is important in this connection that the slurry be kept well agitated to insure a mixture of constant strength. The hydrated lime may be successfully fed directly into the water through a dry-feed machine. Recently, pulverized quicklime, which may be fed through a dry-feed machine, has been put on the market. The use of a saturated solution of lime-water has been almost entirely abandoned due to the construction cost of saturators and because of other difficulties involved.

The soda ash may be fed as a solution or in the dry form. Experience has shown that the dry-feed is to be preferred in larger plants, or where a large quantity of the chemical is required. The point of application with respect to the point of introducing the lime is immaterial. It was formerly believed that when the two were added together there was a waste of soda ash, due to the reaction between the lime and the soda ash to form sodium hydroxide. However, the caustic combines with the free and half-bound carbon dioxide to form soda ash, therefore, there is no waste of chemical. It may be found advantageous to mix the two together and feed out of the same machine, particularly if the water is constant in its characteristics and the proportions of the chemicals needed will be fairly constant.

The feed of the chemicals may be controlled manually or automatically. Some metering device should be available to indicate the flow of water through the plant in order that the operator may vary the feed with the amount of water being treated.

It is important that a thorough mix of the chemicals in the water be obtained. Otherwise the chemicals will stratify and a part of the water will be over-treated while another part will be under-treated. Also a thorough mix will aid in the coagulation of the precipitated hardness and in the efficiency of the sedimentation basin.

CONTROL OF TREATMENT.—To control the lime-soda ash process the following determinations are made on the treated water; phenolphthalein alkalinity, total alkalinity. The methods of determination are given in Chapter XVI. Also given are methods of arriving at the carbonates, bicarbonates, caustic alkalinity, and non-carbonate hardness after the alkalinities have been found. In case of acid waters the total alkalinity is zero and all hardness is non-carbonate.

LIMITATIONS, ADVANTAGES, AND DISADVANTAGES OF THE LIME-SODA PROCESS.—Although it is possible to determine the theoretical amount of lime and soda ash required to produce the desired amount of softening, there are certain limitations on the process which decrease its efficiency. Calcium carbonate, the product of the reaction between the lime and the bicarbonates in the water, is soluble to the extent of about 2 grains per gallon and that amount will remain in solution. If magnesium is present basic carbonates of magnesium may be formed and remain in solution. If the water is high in non-carbonate hardness, the addition of soda ash is conducive to the formation of these soluble basic carbonates. These limitations are of a larger magnitude when the water has a low temperature.

Fortunately these limitations may be overcome to some extent by: (1) treating with excess lime to precipitate the magnesium completely and then converting the calcium causticity to sodium causticity with soda ash; (2) over-treating a portion of the water to obtain maximum softening and then adding raw water to neutralize the excess treatment; (3) the addition of aluminum compounds which aid mechanically in the coagulation of the finely divided precipitate, or may convert the soluble basic compounds into insoluble aluminates, which may be removed by sedimentation or filtration; (4) returning precipitated sludge to the mixing basin to increase the efficiency of crystallization and flocculation of the precipitates; (5) excess lime treatment followed by recarbonation, the water being over-treated with lime and the excess neutralized with carbon dioxide, thus the carbonate hardness may be removed to near the theoretical limit.

There are both advantages and disadvantages to the lime-soda method of softening. The chief advantages are: (1) A reduction in the total dissolved mineral content of the water. For each pound of lime added to the water approximately 3.5 pounds of solids are removed. (2) Lime-soda softening, by increasing the pH, reduces materially the tendency of the water to corrode the distribution system carrying it. It thereby eliminates "red water'' troubles. (3) In many instances softening aids in the purification of water in that a more efficient coagulation of the suspended material is obtained. Where the magnesium content is high the precipitated magnesium hydrate is of such character and bulk as to reduce materially the amount of coagulant required. (4) By maintaining 20 to 50 parts per million of causticity in the settled water for from 4 to 5 hours pathogenic bacteria may be destroyed. (5) Iron and manganese are removed by the treatment, and in many cases color caused by iron and organic matter is adsorbed. (6) The process does not require a raw water free of turbidity, oil, etc.

The main disadvantages are: (1) The resulting large volume of sludge must be allowed for in the design of the sedimentation basin and must be disposed of. This objection is largely overcome where a satisfactory means of sludge disposal is readily available. (2) The operation of the lime-soda softening plant requires close supervision if a satisfactory result is to be obtained. (3) Where recarbonation is not practiced the filtering media and distribution system carrying the water will become coated with a deposit of carbonates of calcium and magnesium. (4) If the original water is high in sodium salts, softening may result in undesirable concentrations of such salts, as in some of the west Texas ''gyp'' waters.

RECARBONATION OF LIME-SOFTENED WATER.—A lime-softened water is supersaturated with respect to the carbonates of calcium and magnesium, and unless it is stabilized, the piping system carrying the water will become incrusted with a deposit of these carbonates. Meters will become clogged. The sand and gravel in the filters will collect a deposit and in time will become cemented together to form large lumps. Recarbonation eliminates these difficulties by converting the excess carbonates into the soluble bicarbonates. A generally used practice with recarbonation is to overtreat with lime to precipitate the magnesium and calcium down to the limit and then to convert the excess lime to calcium carbonate which, in the absence of the magnesium, will precipitate down to about 2 grains per gallon. The reaction is

$$CaCO_3 + CO_2 + H_2O = Ca(HCO_3)_2.$$

From this equation the amount of CO_2 in pounds per million gallons theoretically required to convert the residual carbonate to bicarbonate is 3.7 × $CaCO_3$ (in parts per million). In actual practice some of the gas is lost in the scrubber and by absorption, and so 20 to 25 per cent more will be required.

The carbon dioxide may be obtained from one or a combination of the following sources: the burning of natural or illuminating gas, coke, oil, producer gas, or Diesel engine exhaust gas. For a small plant use of natural or artificial gas will probably prove to be the most advantageous. The equipment required consists essentially of a combustion chamber, a scrubber or washer to clean and cool the gaseous products of combustion, a drier to remove the moisture from the gas to prevent corrosion of the blower equipment, a compressor or blower to supply sufficient pressure to force the gas through the diffuser system, a recarbonation chamber of sufficient size and with sufficient diffusers uniformly to treat the water. In estimating the size of the equipment necessary the volume of inert gases which must be handled in addition to the carbon dioxide must be considered. The inert gases will amount to about 90 per cent of the total volume of gas handled.

Scrubbers may be built of concrete, or of steel lined with brick or concrete. The scrubber and drier are usually built as one unit. It is customary, although not necessary, to build scrubbers of height equal to three times the diameter and to provide 1 cubic foot of scrubber capacity for each 80 cubic feet of gas handled per hour. Two gallons of water are used for washing this volume of gas.

The diffuser system for the gas is usually constructed of ¾-inch galvanized steel laterals leading from a central header. The size of the header will depend on the pressure and volume of the gas being delivered. The laterals are usually placed on one foot centers with ³⁄₃₂-inch holes drilled at 1-foot centers and pointing downward. The total area of the holes should be 80 per cent of the area of the header. Carbonation is apparently instantaneous and a large carbonation basin is not necessary. A basin large enough to accommodate the diffuser system will be large enough for the recarbonation chamber.

COST OF LIME-SODA SOFTENING.—The initial capital expenditure for combined municipal softening and purification plants will vary with the size, current and local prices, etc. For smaller plants, however, the approximate cost will be $50,000 to $60,000 per million gallons per day capacity. This figure is lowered considerably in the construction of larger plants. This expense is about evenly divided between coagulation and sedimentation equipment and the equipment for sand filtration. At many plants only coagulation and filtration are practiced and it will be found that lime-soda softening could readily be incorporated into the process with very little increase in the cost of operation.

At most softening plants the water is softened to a residual hardness of 85 to 100 parts per million. The alkalinity is reduced to 40 to 60 parts per million and the magnesium to around 10 parts per million. If the alkalinity, magnesium and non-carbonate hardness of the raw water are known the cost of softening may be calculated. With lime costing $10.00 per ton and soda-ash $30.00 per ton, the average cost for lime to reduce the carbonate hardness in the Austin softening plant will average 4 cents per part per million of hardness removed per million gallons. The total cost for softening chemicals for removing 100 parts per million hardness averages $4.00 to $6.00 per million gallons.

ZEOLITE SOFTENING.—Zeolite is the term applied to certain complex compounds of sodium, aluminum and/or iron, silicon, with oxygen and water. The mineral is found in nature and known as glauconite or greensand. It is also prepared artificially. The softening zeolites have the ability to exchange sodium ions for calcium and magnesium. By passing hard water through beds of the mineral softening may be accomplished according to the following equation:

$$Na_2Z + CaR = CaZ + Na_2R,$$

where Z represents the zeolite radical and R is any dibasic acid. After a large part of the sodium has been replaced by calcium and magnesium the mineral becomes exhausted. The capacity, or amount of calcium and magnesium that will be removed before exhausting, depends on the type of mineral used. The natural zeolites have a capacity of about 2800 grains per cubic foot of mineral while the artificial or synthetic minerals will range from 6000 to 12,000 grains.

After the mineral has become exhausted it may be regenerated, or have its softening power restored, by reversing the concentrations. That is, the mineral is treated with a strong solution of NaCl (common salt) and the sodium of the salt will replace the exhausted calcium and magnesium, according to the following formula:

$$CaZ + 2\,NaCl = Na_2Z + CaCl_2.$$

The salt requirements for zeolite softening vary slightly with the mineral used but the average requirement will be about ½ pound of salt per 1000 grains of hardness removed.

The chief advantage of the zeolite method of softening lies in the fact that practically all of the hardness may be removed. The operation is simple and requires no trained supervision. There is no sludge to be disposed of, and no feeding and stirring equipment or sedimentation are required. For small plants the initial installation costs will be less than for a lime-soda plant. It is cheaper to remove the non-carbonate hardness with zeolites than with soda ash. At some plants it is found economical first to reduce the carbonate hardness with lime and use the zeolite for the non-carbonate hardness.

The main disadvantages of the process may be listed as: A slight increase in the amount of the dissolved mineral matter in the water. The process must have a raw water free of turbidity, oil, iron, etc. The cost of the chemicals exceeds that in the lime-soda process when treating a water where most of the hardness is due to the bicarbonates. Under some conditions zeolite-softened waters have been found to be very corrosive to piping systems. A high percentage of wash water (5 to 10 per cent of the total) may be required for washing and regenerating the bed.

ECONOMICS OF WATER SOFTENING.—The softening of water should be treated as a problem of economics in that it is one in which it is possible to compare savings and costs in terms of dollars and cents, and to determine whether the saving will justify the investment required. When a municipality constructs and operates a softening plant an appreciable increase in the financial burden falls on the city. The major resultant saving accrues, not to the administration, but to the individual consumer and it is on this basis that the softening plant should be sold to the public.

The saving to the consumer will be in the form of an elimination or reduction of the cost which hard water imposes in various ways. The principal ways are: (1) Extra soap and washing compounds for softening water in the home; (2) harmful effect of hard water on fabrics; (3) expense of a cistern, double plumbing system or home softener; (4) heat losses due to the scaling of hot water systems and steam boilers.

Of these items the most costly one is the extra amount of soap consumed. Stanley[1] has made a study of the savings accruing to towns of 1000 to 20,000 population by softening the supply by 100 to 400 parts per million. As an example of the economy of softening his report indicates that a municipality of 10,000 population, softening a water in conjunction with a rapid-sand filter plant, will have a total purification cost of approximately $20,000 per year. This will include fixed charges, operating and chemical costs, and power, at 2 cents per kilowatt hour for low-service pumpage against a 20-foot head. By removing 200 parts per million of hardness the soap saving to the community will be approximately $18,000 annually or almost enough to pay the entire cost of purification.

An average of the estimates of various workers of the amount of water completely softened per capita per day by the use of soap is 1.2 gallons. It has been determined that 0.2 pound of soap is required to reduce the hardness of 1000 gallons of water 1 part per million. Using these assumptions and taking the average cost of soap at 12 cents per pound, the approximate annual gross saving in soap alone to the consumers of the Austin, Texas, supply was, by removing 100 parts per million, $75,000 in 1935. This amount is more than equal to the total cost of softening and purification.

C. P. Hoover[2] has formulated an equation to show the degree of hardness necessary in any particular water supply in order that the soap saving obtainable by softening will pay for the cost of softening.

$$X = \frac{C - 75D + 75F}{F - D},$$

in which X equals hardness of supply in parts per million; 75 equals lower limit of hardness attainable in municipal softening plants; F equals the soap waste per capita per year per part per million hardness; C equals capital overhead charges per capita per year; D equals cost of chemicals per capita per year per part per million hardness.

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CHAPTER XIV

CORROSION

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Corrosion is that tendency of all metals, when exposed to the elements, to revert to the original sources or more stable forms in which they are found in the earth. It is a process, or processes, by which metals wear away. The products of corrosion are usually in the form of oxides, carbonates, and sulfides. The phenomena of corrosion are the same for all metals and alloys, differing only in degree, but not in kind. It is fitting that this chapter, covering the subject of corrosion as encountered in the water works industry, should treat mainly of those problems and practices of corrosion relating to the ferrous metals.

Theory of Corrosion.—For many years the formation of rust on iron was looked upon as a simple chemical reaction. Extensive research work, however, has proved that it can be complicated by many factors, both internal and external to the metal. Because of these overlapping influences, many different viewpoints were developed regarding the theory of corrosion. It is now generally agreed, however, that when occurring at ordinary temperatures, corrosion is brought about by a driving force between the metal and its environment which is electro-chemical in nature.

The typical chemical reactions of the corrosion process are expressed as follows:

First step—

$$\underset{\text{water}}{H_2O} \rightleftharpoons \underset{\substack{\text{hydrogen}\\\text{ion}}}{H^+} + \underset{\substack{\text{hydroxyl}\\\text{ion}}}{OH^-}$$

$$\underset{\text{metal}}{Fe} \rightleftharpoons \underset{\text{ions}}{Fe^{++}} + \underset{\text{atoms}}{2\,H}$$

Second step—

$$\underset{\text{atoms}}{2\,H} + \underset{\text{dissolved}}{\tfrac{1}{2}\,O_2} \rightleftharpoons \underset{\text{water}}{H_2O}$$

or

$$\underset{\text{atoms}}{2\,H} \rightleftharpoons \underset{\text{gas}}{H_2}$$

Third step—

$$\underset{\text{ions}}{2\,Fe^{+++}} + \underset{\text{dissolved}}{\tfrac{1}{2}\,O_2} + \underset{\text{water}}{H_2O} \rightleftharpoons \underset{\text{ions}}{2\,Fe^{+++}} + \underset{\text{ions}}{2\,OH^-}$$

$$\underset{\text{ions}}{Fe^{+++}} + \underset{\text{ions}}{3\,OH^-} \rightleftharpoons \underset{\text{insoluble}}{Fe(OH)_3}$$

(*Note*: Of the three hydroxyl ions in the last equation, one comes from the equation just preceding, and two from the first equation.)

The above chemical reactions can be explained as follows:

1. The element iron, when in contact with a solution, has a tendency to go into that solution in the form of ions having a positive electric charge. This tendency is known as its solution pressure. All metals exert this pressure to a greater or less extent. In order for the solution in contact with the metal to remain neutral, other positive ions must be displaced, and in this case hydrogen is plated out on the iron surface. The action is shown in the first-step reaction. The film of hydrogen stops further corrosion by insulating the iron from the solution, and also by the tendency of the hydrogen to go back into the solution and oppose the corrosion reaction.

2. For corrosion to continue, the hydrogen film must be removed, and this may happen in two ways. The hydrogen may combine with available dissolved oxygen to form water, or it may escape in the form of gas.

3. After the removal of the protecting hydrogen, the third step takes place and insoluble ferric hydroxide (rust) is formed.

In most cases the occurrence of the second step depends upon the amount of available oxygen to destroy the hydrogen film. In water pipes the presence of dissolved oxygen in the water, therefore, conduces to rapid corrosion.

In acid solutions the reaction is the same except that the hydrogen escapes mainly as gas bubbles, due to its tendency to plate out more rapidly the higher the degree of acidity of the solution. This rapid bubble formation and consequent removal of the hydrogen film is also the explanation for the more rapid corrosion of iron in acid than in alkaline solutions.

FACTORS INFLUENCING CORROSION.—In actual practice there are many factors to be considered with regard to corrosion, and in any one case so many factors may be involved that to determine the true cause of corrosion may result in a very perplexing problem.

Following is a list of well established facts with respect to corrosion of iron:

1. Corrosion takes place more rapidly in acid solutions than in neutral solutions, and less rapidly in alkaline solutions than in neutral solutions.

2. At normal temperatures and in the absence of moisture, iron does not corrode appreciably.

3. Oxygen is essential for corrosion to take place in ordinary water.

4. Products of corrosion consist of ferrous hydroxide next to the metal (dark green or black), and ferric hydroxide (reddish brown) toward the outer layer. In the atmosphere the amount of ferrous rust produced is usually small while under water the amount is usually large.

5. In acid solutions, and in concentrated alkaline solutions, hydrogen is usually evolved from the metal surfaces. In neutral solutions the amount of gas is usually very slight.

6. The rate of corrosion in natural waters usually increases with an increase in velocity of water passing the metal surface.

7. The initial rate of corrosion is usually much greater than after a period of time. This is due to the forming of surface film or coatings of rust that reduce the rate of corrosion. The initial rate of corrosion of a highly polished surface is also usually low.

8. In dilute solutions of neutral salts, particularly chlorides, and at normal temperatures, corrosion usually increases with slight increases in concentration of salts and again decreases as the solution becomes more highly concentrated.

9. The precipitating rust usually carries down compounds containing lime, magnesia, silica, and other insoluble materials in the water. The nature of these precipitating materials may affect the rate of corrosion, depending upon the character of the film or coating they form on the metal surface. A loose coating may increase the local rate of corrosion, a dense and adhering coating may decrease the rate.

10. The composition of ferrous metals, as found commercially, has little effect on corrosion in water or in soils. The composition of commercially found ferrous metals is also of less importance from the standpoint of corrosion than external factors. Composition does, however, play an important part in the corrosibility of ferrous metals in acids and in the atmosphere.

11. Metals, dissimilar in chemical composition, and in contact with electrically conducting solutions may set up a galvanic cell action and produce local corrosion. A small anodic area related to a larger cathodic area will tend to localize the action and increase the rate of penetration or pitting at the anodic area.

12. Corrosion is rarely uniform over a large surface, because of differences in surface conditions which have a tendency to localize the action.

INFLUENCE OF MANUFACTURE AND COMPOSITION.—Influences of manufacture of the ordinary commercially found ferrous metals are of considerably less importance to the corrosion problem than those factors external to the metal. It is not meant that uniformity of texture and composition do not have an influence on the corrosion problem, but when compared to the factor of environment they are vastly less important.

Carbon in cast iron exists in the form of graphite flakes or as combined carbon. The flakes seem to have a mechanical protective influence, but at the same time are cathodic to iron, and may accelerate corrosion. In some soils and waters the metal goes into solution, leaving the graphite flakes, and thus produces the type of corrosion commonly known as "graphitization" of iron. As the percentage of combined carbon is increased, the tendency toward corrosion and graphitization is decreased.

It has been satisfactorily demonstrated that copper in ferrous metals is of considerable importance in decreasing the rate of corrosion when the metals are subjected to atmospheric conditions. The maximum effect is obtained with a copper content of about 0.10 to 0.25 per cent. The explanation for this resistance to corrosion is in the dense character of the rust coating formed and not because of the greater "nobility" of the copper-ferrous metal. It is interesting to note that investigations have disclosed that the unusually long life of many of the ancient iron and steel structures is due largely to the presence of copper in the metals used.

Extensive studies have been made of the influence of copper in under-water corrosion, and, contrary to the atmospheric tests, there seems to be no particular difference between the copper-bearing and non-copper-bearing ferrous metals. In acid solutions, however, the copper content seems to have a definite prohibitive effect.

The influence of copper on underground corrosion has been studied by the U. S. Bureau of Standards and for a 10-year period they have not been able to detect any marked influence on the total amount of corrosion or the localization of corrosion in the ferrous metal group.

The presence of the other elements normally found in commercial iron has but minor significance with regard to corrosion. Ferrous alloys high in chromium and nickel are exceptionally resistant; but for general construction purposes they are still too expensive for extensive use.

From the above facts it appears that for the present, at least, little can be expected from the manufacturer in the way of solving the corrosion problem. Ways and means of controlling the external factors must, therefore, be applied so far as practicable.

RELATIVE CORROSION OF FERROUS WATER PIPE.—In the water works field those problems of corrosion relating to water services, distribution lines, and main supply lines are naturally of more importance than above-ground structural problems. The most significant fact regarding the different ferrous metals, when used under ground or under water, is that, with the bare metal exposed, and all external factors equal, there is no marked difference in the amount of pitting or penetration of corrosion. This fact holds true for copper-steel pipe, steel pipe, wrought-iron pipe, and cast-iron pipe.

The problem of selecting the proper type of ferrous pipe for conveying tap water underground then depends upon the following factors: (1) ability to withstand internal working pressures encountered; (2) ability to withstand external stresses encountered; (3) type of protective coating on pipe, natural or applied, inside and out, and ability of same to withstand corrosion and abrasion in the environment encountered; (4) expected term of service of pipe and most economical cost for that term of service.

The long life of cast iron depends upon the relatively great thickness of the metal and upon a protective skin which fuses upon the surface when it is cast in sand molds. Iron pipe, cast centrifugally, appears to have a surface resistance due to the rapid chilling of the metal.

Cast iron is made from pig iron, and is relatively high in foreign impurities. White cast iron is hard and brittle and low in graphite carbon, inasmuch as most of the carbon has been combined with the iron. Gray cast iron is more malleable, lower in combined carbon than white cast iron, and has a higher graphite content. Wrought iron is a mixture of iron and slag, practically free of carbon, crystalline in structure and malleable. Steel is a crystalline structure consisting mainly of iron and carbon. Steel can be hard or ductile, depending upon the greater or lesser amount of carbon used in processing.

FORMS OF CORROSION ENCOUNTERED IN WATER PIPE.—The forms of corrosion most commonly encountered in water conduits are as follows:

1. Self corrosion or natural soil corrosion.
2. Stray-current electrolysis.
3. Graphitic corrosion (cast iron only).
4. Galvanic corrosion, or contact of dissimilar metals.

Self corrosion takes place under water or when the metal is in contact with moist soil. This type of corrosion depends upon the solution pressure of the metal, and the presence of oxygen to combine with the hydrogen as it is displaced from the water.

Stray-current or electrolytic corrosion occurs when an electric current, other than that generated in the pipe itself, is induced in the pipe and flows from the pipe into the soil or into a less resistant conductor. Corrosion, or pitting, is confined to the spot where the current leaves the pipe. Electric street railways are common sources of stray currents. Electrolysis by stray currents may also be caused by changes in soil conditions along the pipe line. The different soil types form the poles of a battery and the ground water is the electrolyte. This type of corrosion is more likely to be important in long transmission lines but is sometimes noticed in parts of the distribution system.

Graphitic corrosion of cast iron commonly occurs in salt water and in certain types of soil. Stray currents have been known to cause graphitization, but it is known to be caused more commonly by self or soil corrosion. As indicated above rapid corrosion follows the graphite flakes, the metal going into solution and leaving iron oxide, graphite, and the other impurities that are present. The products of corrosion are left in their original shape and form, and unless a close inspection is made, the pipe may seem to be unharmed. Usually on close inspection it will be found that the graphitized section can easily be cut with a knife.

Galvanic corrosion is that form caused by the use of dissimilar metals in contact with each other. When the two metals, each having different solution pressures, are immersed in water, they produce a direct galvanic cell action. One discharges metal ions into solution and the other receives or plates out the hydrogen ions. Common causes of galvanic corrosion include the deliberate use of dissimilar pipe or fitting materials, poor application of metal coatings, improper selection of metal pipe coatings, impurities in the pipe metal, and mill scale left on the pipe surface.

METHODS OF CORROSION CONTROL

PREVENTION IN THE ATMOSPHERE.—In the field of corrosion prevention, many types of paints have been developed that are economical and quite effective on structural work exposed to atmospheric conditions. Standard pigments for such paints include zinc oxide, aluminum-bronze powder, sulfate of lead, lead chromate, carbon, red lead, and iron oxides. Bituminous base paints are generally used where acid conditions exist.

Metal coatings are also successfully employed. These include galvanizing (zinc), tin, lead, copper, aluminum, nickel, cadmium, and chromium. It is important that all metallic protective coatings, cathodic to iron, be free from pin holes, otherwise galvanic action may be set up and prove detrimental to the iron itself.

Other coatings are used in special cases. These include rubber, varnish, lacquer, vitreous enamel, and Portland cement mortar.

PREVENTION OF UNDERGROUND AND UNDERWATER CORROSION.—Corrosion prevention on underground and underwater structures, such as pipe lines, presents a quite different problem from protection against atmospheric conditions. Paints, for example, are not accepted as satisfactory protection due to the fact that they do not stand abrasion well and break down too rapidly. In general, the success of any pipe lining or coating depends upon its ability to insulate the metal itself from any and all of the corrosive factors encountered.

Metallic coatings, other than zinc galvanizing, have been used very little. Zinc, when applied by the hot-dip method, stands up very well when in contact with neutral or near-neutral water but is likely to corrode rapidly in contact with highly alkaline or acid soils. It is most widely used for domestic water systems.

The most common type of coating used on steel or iron pipe in the water works industry is the bituminous coating. Bituminous coatings include refined coal-tar pitch, and asphaltic materials, both natural and artificial. These coatings have proved effective when uniformly applied. Bituminous coatings are always applied hot. When exceptionally bad soil conditions are encountered, the pipe may receive several applications, reinforced with layers of felt and paper to improve resistance to corrosion and abrasion.

One of the best coatings now being used on steel and iron pipe is Portland cement mortar. Cement coating gives a high protective value against all types of corrosion except electrolysis. It is applied to the interior if the water to be carried is corrosive, to the exterior if the soil is corrosive, or to both interior and exterior if conditions require.

Pipe may further be protected against corrosion by properly draining the ditch in which it is laid. Lime may be added to the soil adjacent to the pipe, in order to obtain alkaline conditions.

For protection against electrolysis, insulating joints may be used; the pipe may be thoroughly insulated from the ground; the pipe may be completely shielded with some other conductor; and sufficient electrical return drainage may be established to keep the current away from the pipe.

PREVENTION BY WATER TREATMENT.—The treatment of water to reduce corrosion is fairly simple, and for most waters is relatively inexpensive. The object usually sought is the reduction of acidity, with a resulting higher adjustment of alkalinity and pH value. Normal waters with pH values of 6.5 and below, dissolve appreciable amounts of iron. On the other hand, waters having pH values as high as 9.0 dissolve only traces of iron. Lime, soda ash, and caustic soda are the common materials used to increase alkalinity and raise pH values. Passing the water through beds of crushed limestone has also been practiced. Lime has the disadvantage of increasing hardness, while soda ash (sodium carbonate) and caustic soda (sodium hydroxide) reduce the permanent or non-carbonate hardness of water. Lime, however, is the least expensive of the three materials to use.

Water is also treated in order to deposit a protective carbonate film over the entire pipe surface. This method consists of treating with lime until the water is in chemical balance to calcium carbonate. Water that is slightly super-saturated with calcium carbonate will rapidly deposit that material and form an impervious film over the iron. An excess of supersaturation will result in a heavy deposit and consequent reduction in carrying capacity of the pipe.

Water that is under-saturated to calcium carbonate will reverse the action and the film will be dissolved. For satisfactory results it is necessary that a very accurate laboratory control be maintained on this type of treatment. The VonHeyer marble test is recommended for this procedure.

Treatment with sodium silicate has proved satisfactory in protecting water pipe. Protection is due to the depositing of a siliceous film, or gel, on the metal surface. While the sodium silicate treatment can be applied to cold water, its largest use is in domestic and industrial hot water systems where ''red water'' is the paramount problem.

In order to determine the most economical procedure for corrosion protection for any individual case, it is necessary that all facts be known; and therefore, a general rule cannot be laid down that will apply to the majority of cases.

DOMESTIC AND INDUSTRIAL PROTECTIVE NEEDS.—Problems of corrosion in the domestic field are practically the same as those experienced in the water works field, but the application of preventive methods is sometimes different due to the fact that the problem involves smaller units. For example, copper, lead, and brass pipes are available in smaller sizes, making it possible practically to eliminate the domestic corrosion problem if the individual desires to invest in these more expensive materials. These three metals do not corrode rapidly because of their low position in the electro-chemical solution pressure series and because of the highly protective films they form. Copper pipe has become very popular in recent years for household plumbing, and many cities and water companies have also adopted it for running services to meters.

DOMESTIC WATER TREATMENT.—When steel or wrought iron pipes are used for domestic and industrial water lines, the old ''red water plague'' still occurs occasionally, despite the fact that treatment of water with lime or soda ash to control pH values is now quite common in water plants.

Red water, or ferrous pipe corrosion, in closed cold and hot water systems can be treated in different ways. The use of sodium silicate to form gel coating has already been mentioned. The water supply may be treated for the removal of oxygen by a chemical process called ''deactivation,'' which consists of passing the water through a container filled with readily corrosible iron, as filings or turnings, on which the water exhausts its oxygen or other corrosive constituents. Another treatment is termed "de-aeration" and is accomplished by physical means. This treatment can consist of heating the water to drive out dissolved gases, or by the application of vacuum, or it may be a combination of both heat and vacuum. The problem of boiler corrosion is treated in Chapter XV.

PASSIVATORS.—Treatment with passivators, also known as passivifiers, has proved to be practical in limited fields, as hydraulic elevator systems, cooling systems, or similar systems where a limited volume of water is recirculated. Passivators are materials that produce protective films on metal surfaces. Their effect is regarded as one of the most unusual phenomena in the field of corrosion control and when it is better understood may prove to be far more valuable than at present. The initial rate of corrosion, when passivators are used, is usually high and drops off according to the effectiveness of the passivator used. The chemicals used as passivators are chromates, chrom-glucosates, amines, silicates, phosphates, and tannates.

Where unusual corrosive conditions are encountered in the industrial field, it may become necessary to use materials high in copper, tin, nickel, or chromium. Of late an asbestos fiber-cement pipe (Transite) has been developed that can also be used where unusual corrosive conditions exist. This type of pipe is also available in larger sizes for general use in the water works field.

ELECTRIC GROUNDING.—The common practice of grounding motors, phones, and radios to water pipes has been known to create corrosion. Cases have been investigated where copper pipe was involved, and copper was detected in water samples that were collected and analyzed. Cases have been reported and claims made, that decided copper metallic tastes were noticeable. Claims have also been made that cast-iron bottoms of water meters have been seriously corroded, due to electric grounds. There is a serious need at the present time for more scientific information on this problem, and if it is proved that grounding is a serious problem generally, then ways will be found to stop this common practice.

CONCLUSION.—In concluding this chapter it must be stated that the necessity for brevity and the very great scope of the subject have prevented presentation of the numerous details that are necessary for a comprehensive understanding of the important subject of corrosion. For this reason, the reader is urged to study the references given at the end of the chapter where those details are to be found.

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Chapter XV

WATER REQUIREMENTS FOR INDUSTRIAL USES

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Industrial uses of water may be defined as those in which the water is used as a raw material, or as a part of a manufacturing or commercial process, and may include water for ice manufacture, boiler-feed water, carbonated beverages, laundries, cooling water, brewing, textile plants, paper mills, wool-scouring plants, and many other processes.

The quality of water required for industrial purposes naturally varies widely with the needs of different plants, say from a wholly untreated water to one that is of even higher quality than is satisfactory or acceptable to the general public.

In most cases the manufacturing or commercial plant requiring water of a better quality than that served the general public is expected to provide such extra treatment at its own expense. In some instances plants are willing to use raw river or lake water, if their processes do not require treated water, or they may provide their own treatment, provided in each case they can get it at a lower price.

Occasionally the city water plant provides the extra treatment. This may be done because it is felt that the general consumer is also benefitted, as in the case of softening, or it may be done as an inducement for the location of a factory and the general upbuilding of the community.

The operator of a water plant cannot be expected to be an expert on all the complicated questions of water quality and treatment involved for all manufacturing plants, but he should be familiar with some of the main requirements.

Carbonated Beverages.—Water for bottling works must, of course, meet the standard for bacterial quality and should have a very low bacterial count. The syrups used, and the long period of storage, at times present a good medium and favorable conditions for bacterial after-growths. The water should be free from algae of all kinds, since some types of algae may also continue to grow after bottling. It should be free from organic matter, should be sparkling clear, and of a good taste. It should be free of iron and manganese, since these are apt to precipitate and cause discoloration of the product and staining of bottles. The amount of iron and manganese permitted is even less than that permitted in drinking water.

Considerable trouble has resulted in some bottling works from the use of coagulated waters which are not in chemical balance or equilibrium. As stated before, some bottled products are not used for several months and excess calcium carbonate and iron and aluminum oxides may crystallize from solution upon standing to form a noticeable precipitate, or cause a milky, cloudy appearance. Such troubles may be due to improper dosing or insufficient mixing and it is believed that they are more frequent than is generally recognized. In all probability they exist intermittently in a good many plants.

Cases of trouble have been experienced in bottling plants from wild yeast spores entering the water from air used in air-lift wells. These cause fermentation and spoilage of the product. This difficulty can be prevented by proper air filtration at the intake of the compressor.

A change in treatment processes may cause adherent scale or products of corrosion to be loosened from the mains whence it will be carried into the bottling works, thus causing trouble, particularly if the water is used without treatment at the works.

Some bottling plants sterilize all water by hypochlorite of lime and filter it through sand, activated carbon, or both, to kill and remove all bacteria, algae, and tastes. The filters used are either of the pressure variety or the type using paper disks. After-precipitation of calcium and magnesium carbonates is sometimes guarded against by treating the water as above and then storing it for considerable periods to permit any precipitation to take place. Distilled water is used for bottling in other plants.

BREWING.—The quality of water used in brewing is an important factor in the quality of the product obtained. It is said that the fame of certain ales brewed in England is due to the characteristics of the water used in their production. The water used in brewing should, of course, meet the standards for drinking water. Some of the other qualities of a good water for this purpose are listed below:

1. It should be free from sediment, color, iron, and manganese. The allowable amounts of iron and manganese are less in water for brewing than might be permissible in a water used for general consumption. These substances may stain the product and also the bottles and equipment around the plant.

2. The water must be bacteriologically pure and free from all tastes and odors, including that of chlorine.

3. The water must be in chemical equilibrium, that is, nothing may precipitate upon standing, as this might cause a cloudiness in the liquid or sediment in the bottles. Chemicals used in treating water sometimes precipitate after the water has passed through the plant. This must be guarded against carefully in a water that is to be used for brewing.

4. The water should be practically neutral so far as pH is concerned.

5. The water must contain a minimum amount of carbonate hardness and must be low in sodium bicarbonate.

6. The sodium chloride content should be below 275 parts per million.

7. The water should contain a fairly large amount of calcium sulfate. Four or five hundred parts per million are not excessive. This requirement is somewhat unusual since calcium sulfate is generally not considered as a desirable constituent. Its presence in a water, however, favors enzyme action which is an important part of the fermentation process, and it thereby increases the yield and helps to produce a light-colored beer.

8. Water used for brewing should be free from organic matter. The occasional presence of organic matter has caused a large amount of spoilage of the product and must be carefully guarded against.

The above requirements cover the water used in the actual brewing processes. Usually large amounts are also used around the plant as boiler-feed water, for cleaning purposes, etc. The water described above would be suitable for all such purposes except, perhaps, as boiler-feed water. The requirements for this will be covered in the following article.

Water can be freed of sediment, color, tastes, odors, hardness, iron, manganese, and bacteria by the ordinary processes of water treatment described in other chapters, and thereby made suitable for brewing purposes. If the calcium sulfate content is too low calcium sulfate should be added to raise the amount to a reasonable figure.

Usually breweries will have chemists available who will test the water and prescribe the treatment if the water supply is unsatisfactory. The water plant operator should, however, understand some of the problems of the brewery in order to give as satisfactory a water as can be secured with the treatment processes available in his plant.

BOILER-FEED WATER.—A proper quality of water for boiler-feed purposes is of considerable importance in any community. While there may be few large boilers in a town, there are usually many small boilers used in laundries, dry-cleaning and pressing establishments, ice plants, central steam and hot water heating plants and numerous smaller boilers. In addition, some of the qualities which make a water suitable for boiler-feed purposes will cause trouble in domestic hot water heaters, such as tendency to corrode the metal and to form scale. Some of the troubles in boilers caused by improper feed water are scale, corrosion, caustic embrittlement, foaming, and priming.

Boiler-feed water for moderate pressures should be clear, entirely free from non-carbonate hardness, have a total hardness not exceeding 35 parts per million, with practical freedom from oil, carbon dioxide, free oxygen, free acids, and organic compounds. Boiler-feed water for extremely high pressure boilers should have practically all the hardness removed. It should have an alkalinity (expressed as sodium carbonate) to sodium sulfate ratio as prescribed by the American Society of Mechanical Engineers, as shown in the following table:

Boiler Pressure	Alkalinity	Sodium Sulfate
0–150 lbs.	1	1
150–250 lbs.	1	2
250 lbs. and over	1	3

Hard dense boiler scale causes less heat loss than porous scale but may be more difficult to remove from tubes by mechanical means. Scale causes a reduction in efficiency, since the scale acts as an insulator to prevent the transfer of heat. Scale is also the cause of overheating and damage to boiler plates, sheets and tubes. The commonest scale-forming compounds are calcium carbonate, calcium sulfate, magnesium carbonate, and magnesium sulfate.

Corrosion in a boiler may be due to one or several of many causes. Some constituents of water which will cause corrosion are mineral acids, salts which produce mineral acids by oxidation, organic acids from decayed vegetable matter, free carbon dioxide, and dissolved oxygen. Some of the dissolved minerals causing corrosion are sodium carbonate, sodium chloride, magnesium chloride, and calcium chloride. The dissolved minerals should be removed, if possible, by softening and the proper control of alkalinity. Free carbon dioxide may be partially removed by aeration and the balance by lime treatment, or it may all be removed by lime treatment. Dissolved oxygen may be removed either by chemical or mechanical means. The commonest chemicals used for oxygen removal are tannin compounds, ferrous salts, and sulfates. Mechanical deaerators are used to drive off the oxygen by heating the feed water.

Caustic embrittlement is a term used to describe weakening changes in the boiler metal caused by the use of water high in sodium carbonate or sodium hydroxide. Conditions favorable to caustic embrittlement usually involve a water with a high pH value. Embrittlement may be inhibited by maintaining a specified sulfate-carbonate ratio in the water, the ratio varying with the steam pressure as tabulated above. Sodium sulfate, sodium bisulfate, or sulfuric acid may be added to correct a water deficient in sulfates. It has been found that the addition of phosphates, tannates, chromates, nitrates, and acetates will retard or prevent caustic embrittlement.

Foaming may be described as the formation of bubbles on the water surface in a boiler. When the amount of these bubbles becomes sufficient to fill the steam space in the boiler they are carried off by the steam, causing wet steam. Foaming is a continuous process, while priming is the sudden formation of bubbles, and is usually caused by improper operation of the boiler. Foaming and priming not only cause wet steam but may result in showing a false water level and thus be the cause of an explosion.

Some causes of foaming and priming are as follows: (1) Improper boiler design, such as limited water area or limited steam space. (2) Variation in load or water level and irregular firing. (3) Boiler water containing a heavy concentration of alkali salts, suspended matter, or organic matter.

Water concentration can be controlled by use of evaporators to evaporate all water used as boiler-feed water, by removing the solids from the water and then returning the water to the boiler, and proper blowdown procedure, by which part of the accumulated solids are removed.

Some of the tests used to determine the quality of boiler-feed water are hardness, hydroxides, alkalinity, carbonates, chlorides, total dissolved solids, and suspended matter.

Methods of water softening used for boiler-feed waters are the cold lime-soda process, the hot lime-soda process, the zeolite process, and the combination lime-zeolite process. Hard water softened to about 35 parts per million by the cold lime-soda process usually contains from 35 to 100 parts per million of caustic alkalinity as sodium hydroxide or sodium bicarbonate. If the zeolite process is used these amounts will probably be slightly higher than the hardness of the raw water. Waters so softened may cause foaming and priming unless a regular blow-off schedule is maintained.

The chemistry of the cold lime-soda process of softening is essentially the same process as that used in municipal softening plants although the steps and equipment are somewhat different. Usually 35 to 100 parts per million of excess lime, and sufficient soda ash to remove all non-carbonate hardness and to convert excess lime to sodium hydroxide, are used, so that the finished water will have a hardness of 25 to 35 parts per million. Unless a long settling time is available, coagulation is sometimes necessary. Sodium aluminate is preferable as the coagulant, since it will not increase the non-carbonate hardness. Aluminum sulfate may be used if the sulfate ratio is low.

The hot-process softener is essentially the same as the cold process except for the addition of heat, which speeds up the action and permits the use of smaller equipment. The heat is not all wasted since it is retained as the water enters the boiler. The principal advantages of the hot-process softener are: (1) Part of the hardness (bicarbonates of calcium and magnesium) is removed by heating. (2) Chemical reactions are speeded up by the heating and are more complete. (3) A more crystalline precipitate is produced which will settle more rapidly. (4) The more rapid or complete reaction permit the use of smaller apparatus and smaller housing, thus lowering the investment in such equipment. (5)

Lower hardness is obtained without the use of excess quantities of chemicals.

The zeolite system of softening is essentially the same as that used in municipal softening. Its advantages are: (1) Practically zero hardness is obtainable. (2) Operation is simple. (3) No sludge disposal is required. Its disadvantages are: (1) Bicarbonates of calcium and magnesium are converted to sodium carbonate. If sodium carbonate is already present and allowed to concentrate, foaming and priming may occur. Sodium carbonate will decompose under boiler pressure into sodium hydroxide and carbon dioxide, which may cause caustic embrittlement and corrosion. (2) Turbidity and oil in raw water must be removed before the zeolite process can be used.

The lime-zeolite process of softening water involves addition of lime, settling, recarbonating, filtering through sand and then through zeolite. This is economical because lime is the cheapest available method of removing bicarbonates of calcium and magnesium, while zeolite is the cheapest method of removing the noncarbonates. No carbon dioxide is formed in this process and all oil and turbidity are removed by the filtration through sand before application to the zeolite. This process is high in first cost of equipment, is rather complicated in operation, and requires disposal of the sludge removed in the lime softening.

Treatment equipment for boiler-feed water usually differs from that used in municipal plants in the size and type of equipment used. Coagulation is not always used. Steel tanks are often used as sedimentation basins and pressure filters are usually used instead of open sand filters. Chemicals are more often fed in the form of solutions unless the quantity of water to be treated is large.

The high alkalinity caused by removing carbonate hardness may damage boilers and equipment unless carefully controlled. It may be neutralized by the use of acid, usually either sulfuric or phosphoric acid.

Boiler compounds are often used and some of them are of benefit if properly used. The exaggerated claims made for some compounds, however, almost amount to fraud. If used under the direction of a competent chemist they may be of benefit in some cases. It has been said, however, that the inside of a boiler is not the proper place to treat water, and it usually is preferable to condition the boiler-feed water if the quantity used is sufficient to justify the cost of the treatment equipment required.

Boiler compounds include many liquids, pastes, powders, and solids. Some of the common ingredients are extracts of various woods and barks, starch, agar, sugar, glycerine, flaxseed, gelatine, graphite, resin, petroleum products, sodium silicate, sodium hydroxide, sodium phosphate, soda ash, sodium chromate, acetic acid, and mercury.

ICE MAKING.—Ice manufacturing plants are numerous in Texas. They are one industry which absolutely requires water of certain characteristics in order to operate satisfactorily. Water to be used for raw-water ice making should be free from all sediment, iron, manganese, tastes, and odors. It should also be low in mineral content and bacteriologically pure. Most waters in the Southwest require some treatment for satisfactory ice making.

Proper treatment can produce a water which is free from sediment, iron, manganese, tastes, and odors and which is pure and practically free from bicarbonates of calcium and magnesium. Sodium bicarbonate, sulfates and chlorides of calcium, magnesium and sodium cannot be removed or altered to permit ice manufacture, if present in large quantities, by any other process except distillation.

Air agitation is necessary in the manufacture of raw-water ice. The air is admitted to the ice can under pressure and keeps the water in motion as the freezing occurs. The motion keeps precipitated chemicals and other solids from being incorporated in the ice crystals and thus concentrates them in the core section of the block and from which they are withdrawn.

The chemicals which cause trouble in manufacturing raw-water ice are discussed separately below.

Calcium and magnesium carbonate.—These compounds cause gritty, dirty, discolored deposits, milky patches and bubbles, and cause shattering of ice at low freezing temperatures. If they total not more than 70 parts per million, lime treatment is not required but treatment with alum is recommended, in order to change the carbonates to the less objectionable calcium sulfate and magnesium sulfate. If the total of the compounds exceeds 70 parts per million, lime treatment should be used. Lime treatment will remove all but 30 to 40 parts per million of the above compounds regardless of the quantity present.

Iron oxide.—This compound causes marked discoloration of the ice in the form of yellow or brown deposits, and also stains any calcium or magnesium deposits. If more than 0.2 part per million (0.012 grain per gallon) is present the water should be treated to remove it. It may be removed by aeration and/or lime treatment. Iron oxide, with its attendant troubles, may be derived from corrosion of the water distribution system, the cans, storage tanks, etc.

Aluminum oxide and silica.—These may cause dirty deposits and sediment. They are not usually present in such quantities as to require treatment but, if necessary, may be removed by lime treatment.

Suspended matter.—If this is the only objectionable impurity present, filtration is the only treatment required. If the water is lime-treated it will be removed by the sedimentation process.

Color.—Analyses may indicate the presence of color but not its cause. Surface water will usually be low in dissolved mineral content, but may be high in the dissolved organic matters which cause color. If color is present, careful treatment of the water is necessary or the color may be set. This subject is treated in Chapter IX.

Sodium carbonate, sulfates and chlorides of calcium, magnesium, and sodium.—Sodium carbonate (actually bicarbonate) in only small quantities, often causes shattering of ice at temperatures below 18 degrees F. It may also cause white butts, may concentrate in the core, retard freezing, and make heavy cores. It does not, however, form a deposit. Lime treatment changes the bicarbonate to carbonate, with but little improvement.

Sodium sulfate, sodium chloride, calcium sulfate, and calcium chloride have the same effects as sodium carbonate and are not changed by lime treatment.

Magnesium sulfate and magnesium chloride give a greenish or grayish tinge to the ice, concentrate in the core, retard freezing and cause heavy cores. They often show up as white spots, and dirty, discolored streaks, but do not form a deposit. Lime treatment changes magnesium sulfate to calcium sulfate and magnesium chloride to calcium chloride.

In considering the above group of chemicals the sodium carbonate can be considered to be 1¼ times as objectionable as the sulfate, and the chlorides about ¾ times as objectionable. The sulfates and chlorides should be totaled separately, then multiplied by the above factors, and then added. An example is given below:

40 p.p.m. sodium carbonate	40 × 1¼ =	50 p.p.m.
50 p.p.m. sulfates	50 × 1 =	50 p.p.m.
20 p.p.m. chlorides	20 × ¾ =	15 p.p.m.
		115 p.p.m.

If the total of the "sulfate equivalent" is less than 171 parts per million, first quality ice can be expected with efficient air agitation and average brine temperatures. If the total is more than 171 parts per million, and less than 256 parts per million, good ice can be expected with slightly higher than average brine temperature or slightly more than the usual volume of air for agitation. If the total is more than 256 parts per million, and less than 342 parts per million, merchantable ice can be made if much more than the usual volume of air is provided, especially during the beginning of the freeze and if brine temperatures of 18 degrees or more are carried. If the total is more than 342 parts per million, and less than 684 parts per million, it is doubtful if acceptable ice can be made and expert advice is required. If the total is more than 684 parts per million merchantable ice cannot be expected.

Lime treatment is commonly resorted to in ice manufacturing for removing the carbonate hardness. The usual processes are mixing, sedimentation, and occasionally filtration, often through pressure filters. Lime treatment leaves 2 to 3 grains per gallon of calcium carbonate, which requires higher brine temperatures to avoid shattering. A process known as neutralizing is sometimes used to convert the calcium carbonate to calcium sulfate by using aluminum sulfate, ammonia alum, or potash alum, to neutralize the alkalinity and convert calcium carbonate to calcium sulfate. This treatment increases plant capacity by permitting lower brine temperatures, prevents deposits in ice and sediment in ice boxes. It also causes less cracking and shattering and the coagulating effect of the alum may remove some sediment and color.

The zeolite process is not used in treating water for ice making, since it converts the carbonate and non-carbonate hardness into other compounds, and may increase these to such a point as to make them objectionable.

Distillation is sometimes resorted to in the manufacture of ice, if water of a suitable quality cannot be obtained otherwise. It is somewhat expensive and is ordinarily found only in those plants which are operated by steam, since the equipment cost is greatly reduced in such a case.

In cases where satisfactory water from the municipal supply is not available ice plants utilize a well supply or a surface source of their own. In this case particular attention must be paid to sterilization, since it has been proved that freezing does not kill some types of bacteria and, therefore, the bacterial quality of the water must be equal to that required for a regular municipal supply.

Equipment for treating water for use at ice plants is in principle the same as that used in municipal water treatment plants, but its is usually much smaller and different in shape. Solution feed is more often used; steel sedimentation tanks and pressure filters are common, except in the larger plants.

Most treatments applied to municipal supplies improve the quality of water for ice making, except zeolite and soda ash softening which, at times, may increase the sodium compounds to such a degree as to cause trouble. Any further treatment required is usually furnished by the ice plant.

COOLING WATER.—The use of water for cooling purposes is an industrial practice which is showing every sign of growing in importance. Cooling water is used in condensers in steam-plant service, air compressors, ammonia compressors, Diesel engines, gas engines, air-conditioning plants, and many other types of service. The location of some industries, as large steam power plants, is often dictated by the location of an ample supply of cooling water.

There are two general methods of using cooling water—one in which the water is allowed to flow through the machine being cooled and then wastes, and the other, in which it is circulated through cooling towers or basins and used over and over. In the latter case the only water required is makeup water to replace that lost by evaporation, and the windage loss.

Many large users of cooling water, as steam power plants, pump cooling water from a river or lake and return it unchanged, except for a higher temperature. In certain important industrial areas the entire stream flow is re-used many times and its temperature increased greatly by the re-use as cooling water.

Naturally, cooling water must be cool in order to remove heat but this coolness is comparative and water can be used if it is the only supply available in large enough quantities, even though it is of fairly high temperature. Naturally cooler water secures the same cooling effect with less power cost for circulating the water.

Sediment in cooling water may cause trouble by causing deposits on the cooling surfaces. Here again a water containing sediment may be used if it is the only one available in large enough quantities.

Corrosiveness is another undesirable feature of cooling water but its use sometimes cannot be avoided, as in condensers of steamships. The corrosiveness may be due to free carbon dioxide, dissolved oxygen, salt, and certain other mineral compounds. Water is sometimes treated to reduce corrosiveness, if the amount required does not make such treatment prohibitive in cost.

Algae in rivers, lakes, and cooling ponds often cause much trouble as they tend to deposit slime on the cooling surfaces and prevent heat transfer.

Scale-forming minerals are apt to cause trouble in cooling-water systems by depositing on the cooling surfaces and insulating against the transfer of heat. More scale is deposited at higher temperatures, so the possibility of using a certain water is partly dependent on the temperatures encountered.

Normally, water continuously reused by being circulated over a cooling tower or through a spray pond, must be of better quality than that used once and then wasted. Since the amount to be furnished is less, being merely the make-up water, it is easier and cheaper to treat the amount added.

A large proportion of the water lost is evaporated in the cooling tower or basin, accordingly it is easy to see that the dissolved mineral matter will be left behind and the percentage of such matter increases. This process is known as concentration. It will cause the water to increase in scale-forming quality, because of the increased percentage of scale-forming minerals, and in corrosiveness because of the increase in the percentage of dissolved corrosive minerals, and in the amount of dissolved oxygen. Regular checks should be made to determine the degree of concentration. If the water becomes too highly concentrated it must be wasted and replaced with fresh water.

Softening by either the lime-soda or the zeolite process is often resorted to in case the water is not fit for use otherwise, or to reduce the amount of concentration. Properly softened make-up water should be used if possible.

Corrosion control is of considerable importance in treating cooling water. All free carbon dioxide should be removed from the original water and the make-up water, a process which is not particularly difficult. Methods are discussed elsewhere. Water being pumped over a cooling tower or through spray nozzles and a spray pond is constantly picking up oxygen from the air, and this must be removed to prevent excessive corrosion. Various methods have been used for this purpose. Addition of a tannin compound is common practice and has proved satisfactory.

Scale-forming compounds must be removed as completely as possible. Details of this removal are included under water softening and will not be repeated here.

Algae and slime growths in cooling-tower basins, spray ponds and equipment may be removed by fairly heavy chlorination. They may be prevented from coming back by continuous chlorination and weak solutions of copper sulfate.

One use of cooling water that is becoming more important every day is for air conditioning. Many systems use cool well water once and waste it to the sewer. This may cause an over-draft on the underground water supply, if other customers are using it, and may also overload the sewer system. Sometimes water from the public distribution system is thus used and wasted. This may overtax the water plant and distribution system, since the load comes on at the time of the customary summer-peak load. The decision between wasting the water and re-using through a cooling tower, etc., often is the result of balancing power costs for recirculation and cost of equipment against cost of water. Modern equipment has reduced the amount of water used in air-conditioning, and by the proper use of such equipment excessive loads will not be placed on the water system.

Available figures as to the amount of water required for air-cooling systems are rather meager. It appears, however, that for office buildings, etc., the daily use per person served is about 50 gallons. This may be cut by installation of water saving devices to about 12.5 gallons daily per person served. Large installations, as department stores, may each use as much water as a population of 2,500 persons. For these reasons some water superintendents advocate a ready-to-serve charge for air conditioning installations, in addition to regular water charges and a sewerage charge. Such large uses may be of great importance when a city's demand is close to its available supply.

OTHER INDUSTRIAL USES.—There are a large number of other industrial uses that require only small amounts of water, and whose water quality requirements are not much different from those for domestic use. No attempt will be made to consider the requirements of these uses in detail but some of them are listed below.

Laundries require clear, soft water, free from iron and manganese. The reason for the need of clear water is obvious. Soft water is required to reduce the use of soap and improve the appearance of the laundered product. Since water softening is cheaper than soap, most laundries soften their water previous to use, if it is hard, rather than soften by soap. The presence of iron and manganese may cause staining of the clothing.

Canneries and meat-packing plants should have a water meeting the standards for drinking water. The presence of any taste or odor may spoil canned goods and cannot be permitted. The water should be free from all organic matter.

Paper making is not an established industry in this part of the country but may become one in the future. A large assured water supply is one of the primary requirements. Mills making newsprint and boxboard require a water free from sediment. They may, however, use a water receiving no other treatment than screening and sedimentation. Mills producing a higher quality of paper require a water that is clear and free from color, iron and manganese, since all of these may tend to color the product. Chlorine or activated carbon may be used to remove color.

Textile mills impose few requirements on water quality, except that it must be clear, colorless, and free from iron or manganese.

SPECIAL EQUIPMENT, LABORATORY TESTS, AND METHODS OF CONTROL.—Most of the processes of water treatment required by industries are similar to those used for municipal treatment plants. The equipment is also similar, although it may differ considerably in size and in methods of operation, primarily because the quantities of water to be treated are usually very much less than in the usual municipal plant. For the same reason less elaborate control equipment and fewer labor-saving devices are employed. Dry-feed machines, for example, are seldom employed in purification plants for industrial purposes, except in the largest plants, since the small quantities usually involved are easier to proportion and feed accurately in solution, and because the solution equipment is usually cheaper.

Coagulation and sedimentation basins are usually in the form of wood or steel tanks. Sedimentation basins of the fill-and-draw type, which are alternately filled and allowed to settle and then emptied, are used much more frequently in small plants for treating industrial water than in municipal plants, which commonly use the continuous type of settling basin.

Pressure filters are employed more in treating industrial water than in municipal plants, due partly to economy in space, reduction in number of times pumping is required, and lower first cost for the smaller units. Usually also, the water is filtered merely to remove inorganic solids and not disease bacteria.

Sterilization is not so often a part of water treatment for industrial plants, although chlorine is sometimes used in the control of algae and slime. When used the equipment is similar to that in municipal treatment plants, except that hypochlorite is probably used more often, principally because of the lower first cost of equipment.

Most of the laboratory tests and methods of control employed in the treatment of industrial water supplies are the same as those used at municipal water treatment plants, except for bacterial analyses, which are not often made. Since the methods are the same they will not be discussed in this chapter.

CONCLUSION.—It may be said that nearly any process used to improve the water supply for domestic and commercial uses will also improve it for most industrial purposes. It is often necessary to give the water further treatment for industrial use but this is usually considered to be the responsibility of the industry requiring the special qualities.

CHAPTER XVI

PHYSICAL AND CHEMICAL TESTS

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The work of a filter plant operator is of far greater importance than the mere task of supervising or operating the filters. He must have a personal interest, not only in the plant and grounds, but more especially in the character of the plant product. He must be able to sell that product, and in order to do so, he must be able to make certain physical and chemical tests that are essential to intelligent observation of the quality of both the raw and the treated water. For it is only by regular testing that he can operate a plant efficiently and economically, be certain himself that its effluent is satisfactory, and be able to prove to both friendly and unfriendly critics that he is adequately performing his duties. Following are descriptions of the more important physical and chemical tests necessary in plant control.

Only the tests most commonly used are described in this chapter. For other tests and methods of making them the reader is referred to ''Standard Methods of Water Analysis'' listed in the references at the end of this chapter. In Appendix C of this Manual will be found methods of making the solutions mentioned.

PHYSICAL TESTS

TEMPERATURE.—A fair, representative sample should be taken, not only for ascertaining temperature but also for making all the following examinations. A knowledge of the temperature of the water is often important properly to regulate the application of coagulants, and the period of coagulation and sedimentation. Operators of air-conditioning plants and those having water-cooled refrigerating machinery find it desirable to have a record of temperatures. The temperature at the time of collection should preferably be expressed in degrees Centigrade to the nearest degree, or closer if more precise data are required.

TURBIDITY.—The turbidity of water is due to suspended matter, such as clay, silt, finely divided organic matter, microscopic organisms, and similar material. The turbidity of water may be determined in one of three ways. A turbidity rod, as designed by the U. S. Geological Survey, can be used, provided a determination of the turbidity can be made in the open where a large volume of water can be tested. This method is very simple and consists in lowering the rod, fitted at its lower end with a platinum wire 1 millimeter in diameter, until the wire disappears from sight when viewed from a point 1.2 meters above the wire. The position of the water surface on the turbidity rod is then observed. The rod is so marked that this position on the turbidity scale gives the turbidity in parts per million. For example, if the rod is lowered to a point where the wire just disappears from sight when the water surface is at the 30 mark on the rod, the turbidity of the water is 30 parts per million. This method is not very accurate as the readings are affected both by the variations in the brightness of the daylight and by the color of the water. The turbidity rod method is no longer given in "Standard Methods of Water Analysis," its place being now largely taken by the Jackson turbidimeter.

The Jackson or candle turbidimeter consists of a graduated glass tube and a support so constructed as to hold the glass tube over a "standard candle." The water to be tested is poured into the glass tube until the image of the candle flame just disappears from view. The turbidity of the water will be indicated by the scale reading corresponding to the elevation of the water in the tube. The method just described is probably a little more accurate than the first one; however, difficulties are sometimes experienced because the candles do not burn at a uniform rate.

Most plant operators prefer the candle turbidimeter and the American Public Health Association recommends it for turbidities from 100 to 1000 parts per million. For turbidities over 1000 the sample is diluted with turbidity-free water until the resultant turbidity is less than 1000. Detailed information on this particular determination may be secured by consulting "Standard Methods of Water Analysis," Eighth Edition, 1936.

For turbidities under 100, comparison with prepared standards is recommended. These turbidity standards may be purchased ready for use, or prepared as follows: A small quantity of fuller's earth (especially prepared for the purpose), is sifted through a

200-mesh sieve. A 1-gram portion of this sifted material is weighed out on an analytical balance and added to 1 liter of distilled water to make the standard suspension, which represents a turbidity of 1000 parts per million. Next, carefully clean fifteen 250-ml. glass-stoppered clear glass bottles and label them 5 parts per million, 10 parts per million, etc., to 200 parts per million, as shown in the column "Degree of turbidity," Table XVII. Then measure the number of milliliters of the standard suspension, as given in the second column into a 250-ml. graduated cylinder and dilute to 250 ml. with distilled water and place the diluted standard in the proper bottle. Care must be exercised to rinse the graduate thoroughly between each dilution. Additional turbidity standards can be made by using proportionate quantities of the standard stock suspension. It is, of course, necessary to shake the standard each time a portion is withdrawn for use, as the fuller's earth settles to the bottom when the suspension is not in use. Growth of molds and bacteria in the standards may be prevented by adding a small amount of mercuric chloride.

TABLE XVII.—QUANTITY OF STANDARD SUSPENSION WITH A TURBIDITY OF 1000, WHICH MUST BE USED TO PREPARE 250-MILLILITER STANDARDS WITH GRADED TURBIDITIES SHOWN

Degree of turbidity parts per million (silica standard)	Number of milliliters of standard suspension to be added with enough distilled water to make 250 milliliters
5 p.p.m.	1.25 milliliters
10 "	2.50 "
20 "	5.00 "
30 "	7.50 "
40 "	10.00 "
50 "	12.50 "
60 "	15.00 "
70 "	17.50 "
80 "	20.00 "
90 "	22.50 "
100 "	25.00 "
125 "	31.25 "
150 "	37.50 "
175 "	43.75 "
200 "	50.00 "

The turbidity of the sampled water is ascertained by placing a portion of the sample in a 250-ml. bottle similar to those containing the standards and then observing which of the standard solutions most nearly approaches the degree of cloudiness of the sample, as determined by looking at a background formed by alternate black and white parallel lines on a board or some other convenient vertical surface. The turbidity of a sample of water may be estimated when the degree of cloudiness does not equal that of any of the standards, by placing the bottle containing the sample between the two standards most nearly matching the sample and then estimating the relative degree of cloudiness of the sample. Thus, the sample may have a cloudiness about midway between that of the standards marked 20 parts per million and 30 parts per million in which case the turbidity should be recorded as being 25. If the turbidity is below 5 the Baylis turbidimeter[1, 2] should be used. This apparatus makes use of light reflected from the suspended solids, thus giving the great sensitivity that is required for testing effluents. The turbidimeter can be made by the operator and directions can be obtained from the references given.

COLOR.—The color of water is due to various materials in solution, although the suspended turbidity occasionally adds an apparent color to water which may add to or disguise the true color. It is, therefore, possible to make two color determinations, namely, the apparent color of the original sample, and the true color of the sample, the latter after the removal of the suspended solids or turbidity.

Apparatus needed: Ten 50-ml. Nessler tubes. Graded standard color solutions can be prepared by adding the quantities of the standard 500 parts per million color solution (the method of preparation of which may be found in Appendix C, Standard Solutions) to the Nessler tubes according to Table XVIII, and then diluting with distilled water to the 50-ml. mark on the Nessler tubes. The individual tubes should, of course, be carefully labelled. Evaporation of the standards should be prevented by the use of cork or rubber stoppers when the tubes are not in use. The standard stock color solutions may be purchased ready for use.

Procedure: The color of a sample is observed by filling a Nessler tube to the 50-ml. mark with the water to be examined. The intensity of the color of the water in this tube is then compared with the various color standards. This is done by looking down through the tubes at a white surface until a standard is found which has the same color as the sample. When the color

TABLE XVIII.—QUANTITY OF STANDARD COLOR SOLUTION (500 PARTS PER MILLION) NECESSARY TO PREPARE GRADED COLOR STANDARDS IN 50-ML. NESSLER TUBES

Color desired parts per million	Number of milliliters of standard color solution to be diluted with distilled water to prepare 50-ml. standards
5 p.p.m.	0.5 ml.
10 "	1.0 "
15 "	1.5 "
20 "	2.0 "
25 "	2.5 "
30 "	3.0 "
35 "	3.5 "
40 "	4.0 "
45 "	4.5 "
50 "	5.0 "

of the sample is between that of two standards, the color can be estimated. Occasionally trouble is encountered when the color of the sample is of a different shade from that of the standards. Under those conditions the determination of the degree of color is somewhat a matter of judgment.

An alternate method for determining color is by the use of standard color discs in a colorimeter or color comparing apparatus. Devices of this kind may be obtained from chemical supply houses.

In water with low turbidity the apparent color corresponds closely with the true color. However, when the turbidity is high, the apparent color obtained, may be misleading. In such cases, in order to determine the true color, the water should first be filtered through clean white filter paper before comparing with the standards. In some instances filtering removes some of the true color. This may be determined by examining the underside of the paper in the funnel, and if it is disclosed, the sediment in the water must be removed by centrifuging or by sedimentation before comparison. Results of color determinations should always be reported as "apparent" or "true."

ODOR.—Odors in water may be associated with the presence in the sample of polluting or otherwise objectionable substances, such as decomposing organic and vegetable matter, microscopic organisms, and odorous chemical compounds.

Taste and odor in water are so very closely allied that it is impossible at most times completely to differentiate between the two. The odor of water is normally determined, however, in the following manner. Shake the sample vigorously in the collecting bottle when it is half to two-thirds full and with the sample at room temperature, remove the stopper, and smell the odor at the mouth of the bottle.

The odor of the hot sample is determined by pouring about 150 ml. of the sample into a flask having a loosely fitted cover over the mouth, and then heating to boiling. The heated sample is removed from the source of the heat and allowed to cool for not more than 5 minutes, and is then agitated by a rotary movement. The odor of the sample is then determined after removing the cover from the flask.

The results are usually recorded in the following terms: aromatic, free chlorine, disagreeable, earthy, fishy, grassy, moldy, musty, peaty, sweetish, vegetable, hydrogen sulfide, etc. The adjectives very faint, faint, distinct, decided, strong, or very strong, are used to qualify the intensity of the odor. The intensity of the odor may be more definitely determined by mixing varying proportions of odor-free water with the sample and then checking the odor of the mixtures. The above procedure is the ''standard'' method of testing for odor. In Chapter IX will be found a later and more accurate method which is coming into use.

CHEMICAL TESTS

ALKALINITY.—The alkalinity of a natural water is due to the presence in solution of carbonates, bicarbonates, and hydroxides of various elements, such as sodium, potassium, calcium, magnesium, and iron. Occasionally, borates, silicates, and phosphates are also found.

The alkalinity of water is determined by the chemical process known as neutralization with acid. This operation is very simple, as it depends upon ''matching'' the amount of unknown alkaline materials in the water with a known amount of acid of known strength. This is accomplished by the use of so-called indicators which are nothing more than dyes which have one color when they are alkaline, and another when they are acid. The point where these indicators change color is the so-called end point. If the proper indicator is used, the amount of acid added will equal the amount of alkaline material in the water at this point. This method of determination is known as titration. Standard acid solutions of known strength (one-fiftieth normal or N/50), may be prepared in the laboratory (see Appendix C). The procedure is, however, somewhat complicated. For beginners it is advised that all standard solutions be purchased from chemical supply houses.

Apparatus and reagents required: One glass burette with stop-cock, for measuring small quantities of the standard acid solution. The burette should be provided with a support.

1/50 normal (N/50) sulfuric acid solution (standard solution).
Solution of methyl orange indicator.
Solution of erythrosine indicator.
Solution of phenolphthalein indicator.
Neutral chloroform.
One 200-ml. Erlenmeyer flask.
One 100-ml. volumetric pipette.
One 250-ml. glass-stoppered clear bottle.

All glassware should be thoroughly washed and rinsed with distilled water before being used.

Procedure with methyl orange indicator: (1) Fill the burette with the standard sulfuric acid (N/50) solution to a point near the zero mark. Place the burette in position in the support, open the stop-cock slightly and allow some of the solution to flow through in order to remove all air bubbles from the tip.

(2) Measure exactly 100 ml. of the water to be tested and pour into the flask.

(3) Add two drops of the methyl orange indicator to the water and shake to mix the indicator with the water. If the water is alkaline, the color of the mixture will be yellow. If the mixture is red, the water has an acid reaction and the degree of acidity has to be tested as described under "acidity." If the mixture has a yellow tint, proceed with the alkalinity test as continued under (4).

(4) Record the level of the standard solution in the burette. Place a sheet of white paper or milk glass under the flask so that the color of the indicator in the sample under examination can be more clearly determined. Let small portions of the standard acid solution drop into the sample of water in the flask and shake after

each addition to distribute the acid. The intensity of the yellow color will grow less with the addition of more acid, until the water takes on a pinkish tinge. The addition of the standard acid should be stopped at this point, and the level of the acid in the burette again noted. The difference between this reading and the one made at the beginning of the test determines the number of milliliters of one-fiftieth normal acid solution required to neutralize the alkalinity. The number of milliliters of acid solution used, multiplied by ten, will give the result in parts per million.

Procedure with erythrosine: With a water which is highly colored, has a high turbidity, or contains large quantities of iron, it is sometimes difficult clearly to determine the end point or change in color when methyl orange is used. Under such conditions the use of erythrosine indicator is advised.

(1) Add 5 ml. of neutral chloroform and 2.5 ml. of erythrosine indicator to 100 ml. of the water to be tested in a glass-stoppered 250-ml. clear glass bottle and shake vigorously.

(2) If the water is alkaline the chloroform layer in the bottle will be pink. If the water is acid it will be colorless.

(3) If the water is alkaline add standard acid solution as described under (4) above until the chloroform layer in the bottle changes from pink to colorless. Multiply the number of milliliters of one-fiftieth normal acid solution used by ten to determine the alkalinity of the water, as in the case of testing with methyl orange indicator. The results should be identical with those obtained when methyl orange is used.

Procedure with phenolphthalein: (1) Add five drops of phenolphthalein indicator solution to 100 ml. of water in the flask. If the solution becomes pink colored, alkalinity due to hydroxides or normal carbonates or both is present in the water.

(2) Add standard acid solution from the burette slowly and in small amounts until the solution becomes colorless. Multiply the number of milliliters of one-fiftieth normal acid used by 10 and note the result as "phenolphthalein alkalinity."

In all cases where the water is quite alkaline, it is permissible to work with 50 ml. of water and then multiply the number of milliliters of acid solution used by twenty to obtain result in parts per million. The results in all cases as described, refer to alkalinity expressed in terms of calcium carbonate.

Use of results: At all water treatment plants where the water is softened it is advisable to run alkalinity tests using either the methyl orange or erythrosine indicator solutions and also tests using phenolphthalein indicator solution. Much information concerning the character of water may be gained by comparing the results obtained when using the various indicators. This information is indicated in Table XIX. Interpretation of the results follows.

TABLE XIX.—RELATIONS BETWEEN ALKALINITY TO PHENOLPHTHALEIN AND THAT TO METHYL ORANGE IN PRESENCE OF HYDROXIDE, CARBONATE, AND BICARBONATE

Result of titration *	Value of radical expressed in terms of calcium carbonate		
	Hydroxide	Carbonate	Bicarbonate
$P = 0$	0	0	T
$P < \frac{1}{2}T$	0	$2P$	$T-2P$
$P = \frac{1}{2}T$	0	$2P$	0
$P > \frac{1}{2}T$	$2P-T$	$2(T-P)$	0
$P = T$	T	0	0

* T = Total alkalinity in presence of methyl orange or erythrosine.
P = Alkalinity in presence of phenolphthalein.
< indicates less than.
> indicates greater than.

If the phenolphthalein alkalinity is zero, only bicarbonates are present. Example: $P = 0$; $T = 40$. Then there are 40 parts per million of bicarbonate, but no hydroxides and no carbonates.

If the phenolphthalein alkalinity is less than one-half the methyl orange alkalinity, normal carbonate, expressed in terms of calcium carbonate, is equal to twice the phenolphthalein alkalinity. Example: $P = 20$; $T = 44$. Then carbonate $= 2 \times 20 = 40$ parts per million. Bicarbonate $= 44 - 40 = 4$ parts per million. Hydroxide $= 0$.

If the phenolphthalein alkalinity is exactly one-half the methyl orange alkalinity, only carbonates are present. Example: $P = 20$; $T = 40$. Then carbonate $= 2 \times 20 = 40$ parts per million. Bicarbonates $= 0$ and hydroxides $= 0$.

If the phenolphthalein alkalinity is greater than one-half the methyl orange alkalinity, the normal carbonate is equal to twice the difference between the methyl orange alkalinity and the phenophthalein alkalinity and the alkalinity due to hydroxides is equal to twice the phenolphthalein alkalinity less the total alkalinity. Example: P = 25; T = 40. (2 × 25) — 40 = 10 parts per million of hydroxide alkalinity. 2 × (40 — 25) = 30 parts per million of carbonate. Bicarbonate = 0.

If the phenolphthalein alkalinity equals the methyl orange alkalinity only hydroxide is present. Example: P = 50; T = 50. Hydroxide = 50 parts per million; carbonate = 0; bicarbonate = 0.

Carbonate (CO_3) equals 0.6 times the normal carbonate expressed in terms of calcium carbonate. Carbon dioxide (CO_2) as carbon dioxide equals 0.44 times the normal carbonate expressed in terms of calcium carbonate. Bicarbonate (HCO_3) equals 1.2 times the bicarbonate alkalinity expressed in terms of calcium carbonate.

ACIDITY.—The acidity of a water represents its content of mineral acids, such as sulfuric, free carbonic acid, or carbon dioxide; and certain salts, such as iron or aluminum sulfate, which will yield hydrogen ions on hydrolysis.

The acidity of water is determined in much the same manner that alkalinity is determined, except that a standard alkaline solution is used instead of a standard acid solution. The same indicator methyl orange is used but, of course, in this case, the color change is from red to yellow, rather than from yellow to red. The end point, or completion of the test when the addition of the alkaline solution is stopped, is the pinkish color mentioned in the determination of alkalinity. The procedure given is for free mineral acids. To determine total acidity, use phenolphthalein as indicator, titrating to the appearance of a faint pink.

A standard alkaline solution of one-fiftieth normal sodium hydroxide is used as a standard solution. This solution is not stable, decreasing in strength due to the absorption of carbon dioxide gas from the atmosphere, which causes a precipitation of sodium carbonate in the standard solution. It is therefore necessary to make up this standard solution frequently, or, in the case of the smaller laboratories, to purchase the standard solution in small quantities from a chemical laboratory supply house. A special burette for alkaline solutions with special attachments for keeping the carbon dioxide out of the solution, is obtainable from laboratory supply houses.

After adding the required number of milliliters of standard sodium hydroxide solution to a 100-ml. sample, multiply the number of milliliters by ten and the result will be the acidity of the water in parts per million, expressed as calcium carbonate. The procedure just given is for free mineral acids. To determine total acidity, use phenolphthalein as the indicator and titrate to the appearance of a faint pink.

FREE CARBON DIOXIDE.—The presence of this gas in water leads to the corrosion of pipes, particularly steam and hot water pipes, and to the solution of any lime salts with which the water may come in contact. The determination of carbon dioxide is of some value, therefore, in determining the corrosive properties of water and also in ascertaining the type of alkalinity existing in the water. See Table XIX.

Apparatus and reagents needed: One 25-ml. burette. One 100-ml. Nessler tube. Forty-fourth (N/44) normal solution of sodium hydroxide. Neutral solution of phenolphthalein indicator.

Procedure: (1) Place 100 ml. of the water in the Nessler tube immediately before the test is made.

(2) Add about ten drops of phenolphthalein solution to the water. If the water contains carbon dioxide, no color will be produced when the indicator is added.

(3) Add sodium hydroxide solution from the burette slowly, mixing the hydroxide solution thoroughly with the water by giving the tube a rotary movement after each addition of hydroxide solution, until a very faint pink color persists throughout the water in the tube. This is the end point. Measure the quantity of standard sodium hydroxide solution used by reading the burette before and after the determinations. The number of milliliters used multiplied by 10 equals the parts per million of free carbon dioxide. To convert carbon dioxide in parts per million to terms of calcium carbonate in parts per million multiply by 2.272.

TOTAL HARDNESS.—Soap Method. The determination of hardness by the soap method roughly approximates the amount of calcium and magnesium in a water, though it actually measures the soap-consuming power of the water. This latter value, however, is of great economic importance and the test may be utilized in the control of the smaller water softening plants, or in testing various waters for hardness.

Apparatus and reagents required: Standard soap solution (it may be purchased from firms dealing in laboratory supplies). Several 250-ml. glass-stoppered bottles. One 50-ml. burette. One 50-ml. pipette. The burette used for making the alkalinity test may be used for this purpose. The bottle and burette must be thoroughly cleaned, rinsed with distilled water or alcohol and completely drained before using. In the case of the burette, it is well to rinse it at least once with the soap solution before filling for use.

Procedure: Place 50 ml. of the water to be tested in the 250-ml. bottle. Add the soap solution to the sample from the burette in 0.2- or 0.3-ml. portions. Shake the bottle vigorously after each addition of the soap solution, continuing this process until a lather remains on the surface of the sample for five minutes with the bottle lying on its side. Near the end of the test, it is well to add the soap solution two or three drops at a time. The number of milliliters of soap solution used is measured from the burette by subtracting the reading of the burette before and after the above procedure. A ''blank'' should be run in the same manner, using 50 ml. of distilled water. This determines the amount of soap necessary to produce the lather itself, and this amount (usually from 0.5 to 1.0 ml.) is subtracted from the amount used in the test on the water itself. This is not necessary if the lather factor has been determined for the soap solution (see Appendix C). The number of milliliters of soap solution used in the test, multiplied by 20, gives the total hardness in parts per million as calcium carbonate.

In testing water containing magnesium compounds by the soap method, care must be taken to reach the proper end point, since magnesium compounds yield a ''false'' end point. To guard against this, the lather *must* persist for 5 minutes. It is essential after the end point has been reached and maintained for the proper time, to read the burette and then add an additional amount of soap solution to be sure.

NON-CARBONATE HARDNESS.—The permanent or ''incrusting hardness'' of a water in which the total hardness is greater than the alkalinity, may be calculated roughly by subtracting the alkalinity obtained (when using the methyl orange indicator) from the total hardness. The result is noted as parts per million expressed in terms of calcium carbonate.

HYDROGEN ION CONCENTRATION.—The hydrogen ion concentration in water is an expression of the intensity factor of acid or alkaline properties as opposed to the quantity factors "acidity" and "alkalinity." Hydrogen ion concentration is usually expressed by the symbol pH.

The theory of the effect of various concentrations of hydrogen ions in water, with reference to the different chemicals used in water treatment, is rather complicated and beyond the scope of this book. In spite of this, however, the actual making of the test for pH is very simple. This is fortunate for the test is of great value for the technical control of water treatment plants. The best point at which the hydrogen ion concentration should be kept varies, and must be determined for each individual water treatment plant.

The test in its simplest form is made by taking a quantity of water to be tested, adding the proper indicator, and comparing the color produced with either a standard color in another sealed tube, or in some cases, glass disks are used. The method using the glass disks is described in the following.

Apparatus needed: One hydrogen ion apparatus, color comparator (one of the simpler forms will do for the smaller plants); two or more color disks (depending on the range of hydrogen ion concentration in the water before, during, and after treatment); standardized indicators corresponding to the color disks.

Procedure: Place the color disk, covering the pH range within which you expect the sample to fall, in the comparator. Fill one of the glass cells with a portion of the sample of water to be examined and put in the comparator. With the graduated tube which comes with the apparatus, measure the volume of water required, and with the pipette measure in the tube the proper volume of the indicator (the indicator must correspond with the color disk in the comparator), pour the mixture in the second cell and place in the comparator.

If the indicator used is within the range for the pH in the water, the actual pH may be read directly by matching the color and shade of the indicator with the color disks in the comparator. In order definitely to determine which indicator to choose, a list of indicators is given, together with their pH ranges, in Table XX. It is, of course, necessary to use the corresponding color disks in the comparator. For instance, a phenol red indicator cannot be used with brom thymol blue color disks in the comparator.

TABLE XX.—SUGGESTED pH INDICATORS FOR USE IN WATER PLANTS

Indicators	pH range	Color change
Methyl red	4.4 to 6.0	red to yellow
Brom thymol blue	6.0 to 7.6	yellow to blue
Phenol red	6.8 to 8.4	yellow to red
Thymol blue	8.0 to 9.6	yellow to blue
Phenolphthalein	8.6 to 10.2	pink to red

When tubes are used for comparison the proper amount of water to be tested is placed in a test tube and the required amount of indicator is added. The color produced is then matched against the standard color of a known pH in a "block comparator" furnished with the apparatus. It should be recognized that prepared indicator solutions for use with glass disks cannot be used with glass tubes, and vice versa. Order supplies of indicators from the maker of your particular apparatus.

RESIDUAL CHLORINE.—The test to determine the presence and parts per million of residual chlorine in water at treatment plants is performed probably more frequently than any other. It is a most important tests. In its simplest form the test consists of adding a reagent, orthotolidin solution, to the water to be tested, and then comparing the color produced with standard color disks in a chlorine colorimeter, or with permanent color standards in Nessler tubes or bottles. The procedure given is applicable to water treated with liquid chlorine, chloramine, or any of the disinfectant chlorine compounds.

Apparatus required: Chlorine colorimeter, open cell type (or more elaborate outfit if desired). Orthotolidin reagent solution.

Procedure: To 100 ml. of the water sample to be tested, add 1 ml. of the orthotolidin reagent, mix, and permit to stand 5 minutes. Fill the cell fitted with the clear glass disk, with water containing orthotolidin, and fill all the other cells with water not treated with the reagent. Compare the color of the treated sample with the disks in the cells containing untreated water. If the color of the sample being tested falls between the colors of two disks, proper allowance must be made in interpreting the result. The various cells are so marked that the result is expressed directly in parts per million of residual (or excess) chlorine.

When using the Nessler tube method the procedure is the same except that the entire 100 ml. is placed in a Nessler tube and compared with known permanent standards in Nessler tubes. The method of preparing the orthotolidin reagent and the permanent standards is shown in Appendix C.

THE "JAR" TEST.—This is a procedure for determining the most efficient and economical dosages of coagulants. The apparatus required is a stirring stand, with a small electric motor and five glass jars each of approximately 2 quarts capacity. Figure 18 shows a stand as recommended by Professor E. P. Schoch. The motor need not be over 1/20 horsepower, electric fan motors have been used for the purpose. The vertical rods or shafts may be of 3/8-inch brass tubing with the blades fastened to them. The blades may be of sheet brass, about No. 20 gage, and 2 × 4 inches in size. The supports for the shafts may be of steel pipe just large enough to allow the shaft to turn freely inside it. The bearing for each shaft may consist of a piece of steel pipe soldered to the brass shaft and turning on the edge of the supporting pipe. The bearing screws into a flange which is attached to the wooden pulley. The belts may be small round leather belting or stout cord.

The test is made as follows: Place in each of the jars 1000 ml. of the water to be tested. In each jar varying amounts of the coagulant are placed, the middle jar receiving the amount which the operator estimates as being just enough for clarification. Next add to each jar the amount of lime (if needed) to give each jar its proper pH value (as previously determined) plus as much more as the coagulant requires. The mixtures are stirred for 30 minutes and then allowed to stand at rest for 1 to 3 hours. They are examined from time to time to ascertain the least amount of coagulant which will bring down all the suspended matter. Flocs from various chemicals and mixtures settle at varying rates, but the liquid above the floc should be clear. For a plant operating without a filter, the floc should settle so readily that the whole sample will be clear in 1 hour.

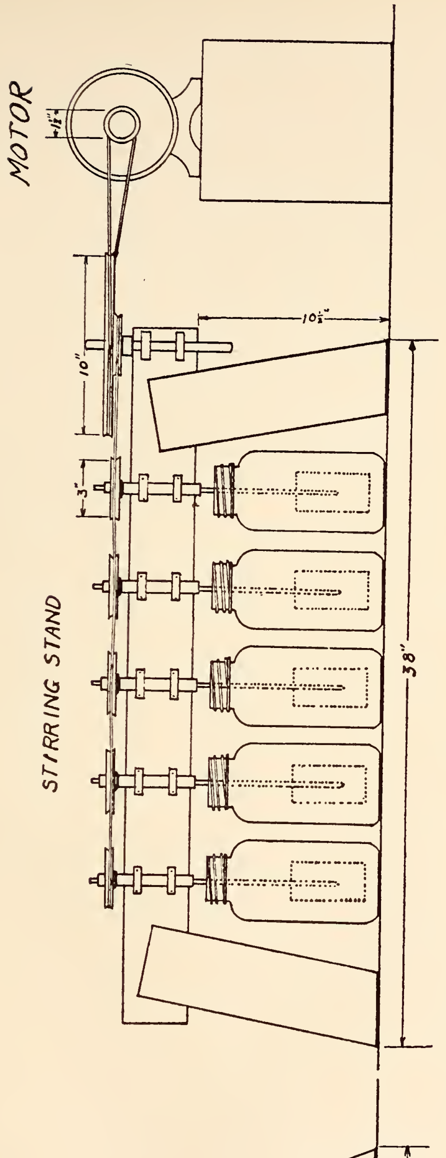
MOTOR
1½"
10"
3"
10½"
STIRRING STAND
38"
12"

FIG. 18. Stirring Apparatus (University of Texas Bulletin No. 3014).

DETERMINATION OF FILTER SAND CHARACTERISTICS

DETERMINATION OF UNIFORMITY COEFFICIENT AND EFFECTIVE SIZE.—In Chapter X allusion was made to the important specifications of filter sands, effective size, and uniformity coefficient. The water plant operator may find it necessary to check these qualities of sand purchased for new units or to replace old sand. Accordingly a method of sand analysis is given here. For a more complete discussion see the "Water Works Practice" listed in the references at the end of this chapter.

Procedure: Standard sieves, which are purchaseable from laboratory supply houses, are used. The sieve-mesh sizes of Table XXI are recommended, although other sizes are sometimes used.

TABLE XXI.—SIEVES USED IN ANALYSIS OF FILTER SANDS

Meshes to linear inch	Opening in millimeters
10	1.651
14	1.168
20	0.833
28	0.589
35	0.417
48	0.295
65	0.208
100	0.147
200	0.074

It is necessary to know the exact sizes of the openings so that the sand sizes can be ascertained. Take a 100-gram sample of the dried sand and shake it through the nested sieves until a thorough separation of each size has been made. Carefully weigh each portion retained on the various sieves. From the weights retained on each sieve, the percentage *passing* each sieve is calculated. Co-ordinate paper, either of the semi-logarithmic or ordinary type is then prepared, with mesh openings shown on the abscissa or horizontal scale and the per cent passing on the ordinate or vertical scale. The per cents passing are plotted opposite the corresponding mesh sizes and a curve is drawn through the points. Where the curve passes through the 10 per cent horizontal line the effective size is read below. Next read the size where the 60 per cent line crosses the curve. This size divided by the 10 per cent size, gives the uniformity coefficient.

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CHAPTER XVII

BACTERIOLOGICAL EXAMINATION OF WATER

BY I. M. LEWIS

Department of Botany, University of Texas

OBJECT OF BACTERIOLOGICAL EXAMINATION.—The object of a bacteriological examination of water is to determine existence of pollution with organisms of intestinal origin, rather than presence of the actual germs of water-borne disease. Pollution is indicated by the presence of certain groups of bacteria which occur normally in the intestinal tract of man and warm-blooded animals. We refer to such groups as *indicator organisms.* The principal group is known as the coli-aerogenes group or simply colon bacteria. Since *B. coli* (*Escherichia coli*) is one of the most common members of the group, many water bacteriologists use this name to designate the entire group. Although colon bacteria are not themselves harmful, they indicate the dangerous possibilities in the water supply, for the colon organisms may at some time be accompanied by disease germs which have been excreted with them. This is borne out by experience, which has amply shown that the safety of a water supply can be judged by the presence or absence of colon bacteria. Accordingly the methods of water analysis are largely based on this test. Other tests which may have supplementary value in certain cases will also be included in this chapter.

The methods most commonly employed are those of the American Public Health Association. These methods are published in "Standard Methods of Water Analysis," Eighth Edition, 1936. This publication is for sale by the Association, 50 west 50th Street, New York, N. Y. It should be available in every water works laboratory for reference purposes.

The present chapter has been prepared for the use of individuals who have limited training and experience in bacteriological methods. A certain amount of technical skill must be acquired in order that reliable results may be obtained. The beginner will find it highly desirable to attend a short course or to visit a laboratory where daily routine analyses are performed. In any case the individual to whom the bacteriological tests are entrusted should understand that his responsibilities are great. Unless it is certain that he has the necessary skill or the capacity to acquire it, and appreciates the responsibility, the work should not be assigned to him.

EQUIPMENT AND SUPPLIES.—A list of necessary equipment and supplies will be found in Appendix B. It is based on the assumption that bacteriological tests are to be carried out daily at the water plant. The catalog numbers apply to the catalog of the Central Scientific Company of Chicago. The prices are subject to change and have not been included. Several other firms, also listed in Appendix B, will furnish bids on the same equipment if requested to do so.

PRELIMINARY PREPARATION

PREPARATION OF GLASSWARE.—All glassware must be cleaned thoroughly before use. Test tubes and Petri dishes containing cultures should be sterilized, either by boiling or autoclaving. Wash thoroughly with soap and water and rinse with running tap water. All glassware should be allowed to stand until dry before further preparation.

Test tubes and flasks are to be stoppered with cotton plugs prepared from a good grade of non-absorbent cotton. Pipettes and Petri dishes are placed in metal boxes.

All glassware requires sterilization in a hot air sterilizer at a temperature of 160 degrees C. for at least one hour and preferably two hours. Bottles with screw caps may be sterilized by heating in an autoclave at 15 pounds pressure for 30 minutes. The caps should be left partially unscrewed during sterilization.

PREPARATION OF CULTURE MEDIA.—The preparation of culture media is greatly facilitated by the use of dehydrated products prepared by the Difco Laboratories, Detroit, Michigan. These products have the advantage of uniformity and ease in preparation. Full directions for preparation and sterilization are printed on the containers. A catalog of Difco products containing much valuable information may be obtained free by addressing that company in Detroit.

ANALYTICAL METHODS

PREPARATION OF WATER BLANKS.—Water blanks are used for preparing dilutions of samples which contain large numbers of bacteria. They are necessary for the analysis of raw surface waters. They may be prepared by sterilizing a flask of tap water in an autoclave and measuring out exactly 9.0 ml. or 99 ml. into sterile bottles or test tubes by means of a sterilized pipette or a sterile graduated cylinder. It is also permissible to place a slightly larger volume of water in the tubes or bottles and sterilize in an autoclave. Some loss of water will occur during sterilization, the exact amount varying with different autoclaves and necessitating determination by experiment.

PREPARATION OF DILUTIONS.—To prepare dilutions, shake the sample bottle thoroughly, remove 1 ml. of the sample to be tested and transfer it to a flask containing sterile water. If still higher dilutions are required, shake the dilution bottle or tube and transfer 1 ml. to a second sterile-water flask. Any desired dilution may be prepared by continuing in like manner. A fresh pipette must be used for each transfer.

PLATING METHODS.—To plate from a sample or dilutions, shake the bottle thoroughly, remove 1 ml. and transfer it to a sterile Petri dish. Pour in about 10 ml. of agar which has been melted by boiling and has cooled down to 42 degrees C. Mix the water and agar by rotating and tilting the dish. Let the plate stand several minutes to harden, and then invert and incubate. Certain precautions must be observed. Operate on a clean table which has been wiped off with a damp cloth. Avoid drafts of air and raise the top of the Petri dish just enough to permit insertion of pipette and mouth of agar tube. Flame the mouth of the test tube before pouring the agar. Prepare a control plate by plating 1 ml. of sterile water. If the control plate remains sterile it may be assumed that all colonies in the plates from the sample or dilution developed from bacteria contained in them. Growth in the control plate indicates poor technique and results on the sample are worthless.

AGAR SLANTS.—The agar used for plating is also employed in making slants. The melted agar is placed in test tubes, approximately 8 to 10 ml. per tube. The tubes, after being stoppered with cotton, are sterilized in the autoclave. After sterilization the tubes are placed in an inclined position so that the upper surface of the solidified agar will form a slant, with its upper edge at least 1 inch from the stopper. After the agar has solidified, the tubes may be stored in a refrigerator until needed.

The agar slants are inoculated as follows. An isolated colony of the type desired is chosen and a small amount of material is fished from it by means of a platinum needle. The needle has first been sterilized by heating it to a cherry red in an open flame and then allowing it to cool. The mouth of the agar-slant tube is flamed and then the material from the needle is streaked on the surface of the slant, care being taken not to cut the surface of the agar. The slant is then incubated at 37 degrees C. for 18 to 24 hours.

THE GRAM METHOD OF STAINING.—Organisms for staining by Gram's method are cultivated on slanted agar for 18 to 24 hours. A film is prepared by placing a loopful or two of water on a perfectly clean and flamed glass slide, transferring a bit of the growth from the slant to the water drops and spreading out to form a film. Slides are easily cleaned before use by rubbing up some Bon Ami and spreading on the slide. Let dry and polish off with a clean cloth.

When the bacterial film has become completely air dried, pass the slide two or three times through the flame of a burner, film side up, to fix the film and prepare it for staining.

Cover the film with crystal violet solution (crystal violet—1 gram, dissolved in 100 ml. of distilled water).

Add about 5 drops of a 5 per cent aqueous solution of sodium bicarbonate and mix with stain of the slide. Let the stain act for 3 to 5 minutes. Pour off the stain and wash with water. Rinse with iodine solution (iodine—2 grams, dissolved in 10 ml. of normal sodium hydroxide solution; make up volume to 100 ml. with distilled water).

After rinsing off with the iodine solution, cover the film with fresh solution and let stand 2 minutes. Rinse with water and decolorize with a solution consisting of equal parts of 95 per cent alcohol and acetone. The alcohol-acetone is dropped on the slide and permitted to run off. This is continued until the solution which runs from the slide is uncolored. About 30 seconds is generally required. Let film dry again and then cover with basic fuchsin solution (0.1 gram basic fuchsin dissolved in 100 ml. distilled water) for 30 seconds. Wash off stain with water and blot dry. Add a drop of immersion oil and examine with oil-immersion objective.

Organisms may be divided into two classes by this method. Gram-positive organisms are stained blue while Gram-negatives are red. All colon bacteria are Gram-negative.

BACTERIOLOGICAL TESTS

THE TOTAL PLATE COUNT.—Plate 1 ml. from the sample or appropriate dilution. Waters containing not more than 300 bacteria per milliliter require no dilutions. In cases where large numbers are to be expected, such as raw surface water, plate sufficient dilutions to insure that some will contain not less than 30 nor more than 300 bacteria per milliliter.

Incubate the plates at 37 degrees C. for 24 hours and count the colonies. Counting is facilitated by the use of a reading lens. Results are to be recorded as the number per milliliter of the original sample. This count is based on the assumption that each colony comes from a single organism. Water of high quality should not contain more than 100 bacteria per milliliter.

PRESUMPTIVE TEST FOR COLON BACTERIA.—Shake the sample thoroughly and transfer 10 ml. to each of 5 fermentation tubes containing 30 ml. of sterile lactose-peptone broth (Bacto dehydrated). If gross pollution is indicated inoculate 5 fermentation tubes containing 9 ml. with 1 ml. of the sample and similarly 5 tubes with dilution 1 : 10, 1 : 100, etc.

Incubate all tubes for a period of 24 hours at 37 degrees C. and examine for gas formation. A column of gas appearing in the inner tube within 24 hours constitutes a *positive presumptive test.* If no gas is formed, or only a bubble, return the tubes to the incubator for an additional period of 24 hours. If at the end of this period no gas has been formed, the test is *negative.* If gas is present at the 48-hour reading, but not at 24 hours, the test is *doubtful.*

THE CONFIRMED TEST FOR COLON BACTERIA.—Positive and doubtful presumptive tests require confirmation, either by plating from the tubes or transferring material from them to a confirmatory liquid medium. The writer prefers confirmation by the plating method.

Prepare plates of eosin-methylene blue agar (Bacto dehydrated, Levine's formula). The addition of 0.5 gram of granulated agar to each 100 ml. of the medium increases its firmness and is desirable when surface inoculations are to be made.

Shake the fermentation tube gently, remove one loopful, deposit it on the surface, and spread out uniformly with the loop needle or a bent glass rod. Invert the plate and incubate at 37 degrees C. for 24 hours. It is recommended that tubes showing gas from the smallest amount of water employed in the presumptive test be chosen for confirmation. The occurrence of colonies typical of the colon group constitutes positive confirmation, although for a complete test further procedure is necessary.

Note: Colonies of the *B. coli* type are dark in color, flat, and characterized further by a metallic sheen on the surface. Colonies of *Aerobacter aerogenes* are larger, more elevated, pink colored with a purplish cap, and usually with little or no metallic sheen. Colonies with other characteristics such as white, pink or blue color are not significant. Plates are not satisfactory for study unless some of the colonies are well separated.

THE COMPLETED TEST FOR COLON BACTERIA.—Select two typical colonies, preferably of the *B. coli* type from the eosin-methylene blue agar plate, or if no typical colonies are present, select two or more which are the most nearly typical. Make transfers from each to a tube of slanted agar and also to a lactose broth fermentation tube. Incubate all cultures at 37 degrees C. for 24 hours. If gas has not formed, return the fermentation tubes to the incubator for an additional 24-hour period. Prepare films from those 24-hour agar slants which correspond to the fermentation tubes in which gas has formed, stain by Gram's method, and examine with oil immersion objective. If the agar cultures are wholly of Gram-negative, non-spore forming rods, and the corresponding lactose broth cultures contain gas at 24 hours, the completed test is *positive,* since all organisms with these characteristics are by definition members of the colon-aerogenes group of bacteria.

If at the end of 48 hours no gas formation has occurred, the completed test is *negative.* If gas has been formed and the organisms are typical as to form and structure, the test is positive. If gas is formed and spores are present, the culture may consist of a mixture of a spore-former and colon bacteria. This can be determined by replating on eosin-methylene blue agar. In the absence of typical colonies it may be assumed that gas formation was not caused by a member of the colon group and the completed test is negative. The presence of lactose-fermenting aerobic spore-formers in water occurs but is not frequent. In such cases the presumptive test is positive, the confirmed test doubtful, and the completed test is negative. False positive presumptive tests are also caused by certain combinations of bacterial species when growing together in lactose broth. Such species are not able to ferment lactose when cultivated separately and hence they do not form typical colonies nor give positive completed tests. An additional cause of false presumptive tests is the presence of spore-forming anaerobes which are capable of causing gaseous fermentation of lactose. This is probably the most important cause of failure to obtain confirmation of positive presumptive tests.

DIFFERENTIAL TESTS WITHIN THE COLI-AEROGENES GROUP.—Many bacteriologists prefer to distinguish between the coli and aerogenes sections of the colon group, and to regard the coli section as a much greater indication of pollution. It is known that cultures isolated from feces of man and animals belong chiefly to this section, while cultures from soil and grains are principally of the aerogenes section. Both types occur in waters but one or the other generally predominates in a sample.

(1) Differentiation on eosine-methylene blue (E.M.B.) agar. The differentiation on E.M.B. agar may be made with considerable accuracy. The colony characteristics have been given in the section on the confirmed test for colon bacteria above.

(2) The methyl red test. Pure cultures prepared for the completed test above may serve for this test. Inoculate a tube containing 5 ml. of medium (Clark and Lubs, Bacto dehydrated) and incubate 4 days at 37 degrees C. At the end of the incubation period add 5 drops of methyl red indicator solution. The indicator solution is prepared by dissolving 0.1 gram of methyl red in 300 ml. of alcohol and diluting to 500 ml. with distilled water. A distinct red color denotes a *positive* reaction, a distinct yellow is *negative* and an intermediate color is *questionable.* The coli section is almost uniformly methyl red positive, and aerogenes negative, while some intermediate strains give doubtful reaction.

(3) The Voges-Proskauer test. Inoculate a tube containing 5 ml. of medium (Clark and Lubs, Bacto dehydrated) and incubate 48 hours at 37 degrees C. Add an equal volume of 10 per cent potassium hydroxide solution and return the tube to incubator. After one hour shake the tubes vigorously till a foam is produced,

as the reaction is facilitated by aeration. Place in a 37 degree C. incubator and examine periodically. If no change in color occurs by the following day the test is *negative.* A *positive* reaction is characterized by the appearance of an eosin-like pink color.

Many workers have attempted to hasten the reaction by various means. The writer prefers the modification of Barritt. To 1 ml. of the culture, prepared and incubated as above, add 0.6 ml. of a-napthol solution (5 per cent absolute ethyl alcoholic solution) and 0.2 ml. of a 40-per cent aqueous solution of potassium hydroxide.

Shake the tube well and apply gentle heat. Pink color appears within 2 to 5 minutes when positive. Maximum coloration develops in 1 hour and persists from 4 to 24 hours. Strongly positive cultures are deep crimson while weakly positive cultures are rosy pink. The Voges-Proskauer and methyl red tests generally correlate. The coli section is methyl red positive and Voges-Proskauer negative, while the aerogenes section is the exact opposite. Cases occur occasionally in which either double positive or double negative reactions result. Such reactions are probably due at times to mixed cultures.

DIFFERENTIAL TESTS WITHIN THE COLI SECTION.—The coli section (commonly referred to as *B. coli*) may be divided into two groups by cultivation in a synthetic medium containing citric acid as the sole source of carbon food (Koser's sodium citrate medium, Bacto dehydrated). The medium is placed in test tubes in 5-ml. amounts and sterilized.

Cultures to be tested are first cultivated on agar slants. A suspension is prepared by rubbing up some of the growth in a tube of sterile water. Inoculate the citrate tubes with a loopful of suspension and incubate at 37 degrees C. for 72 to 96 hours and examine for growth. Some strains grow and cause clouding of the medium while others make no growth and the medium remains clear. Cultures derived from feces are not able to grow in this medium while cultures otherwise identical but derived from soil and some waters grow vigorously. It has been proposed that the name, *B. coli,* be limited to the citrate negative strains and the term, *Citrobacter*, be employed to designate the citrate positive strains. The presence of *B. coli* in water is regarded as of much greater sanitary significance. It is doubtless possible by means of this test to distinguish between fecal and non-fecal strains of the coli section.

The method has not, however, been looked on with great favor in the routine examination of water supplies.

MODIFICATION OF STANDARD TESTS

MODIFICATION OF THE PRESUMPTIVE TESTS.—Many workers in research laboratories have sought to improve on lactose-peptone broth as a culture medium for the presumptive test. The principal causes of false positive presumptive tests have been noted in the section on differential tests above. The chief causes appear to be the presence of lactose-fermenting spore-formers, either aerobes or anaerobes. Modification of the medium have been aimed, therefore, at restraining these organisms, while permitting colon bacteria to grow unhampered. Various chemicals have been tested and many claims have been made for the superiority of these new media. Media prepared according to various formulas are available in the Bacto dehydrated series. These are:

Brilliant green lactose bile broth
Crystal violet broth
Formate ricinoleate broth
Fuchsin lactose broth

Whether any of these will be found sufficiently superior to warrant substitution for plain lactose-peptone broth as a presumptive test medium depends on the experience of workers engaged in routine examination of water under widely varying conditions. It is desirable, therefore, that such workers make parallel tests using some or all of the above media.

MODIFICATIONS OF THE CONFIRMED TESTS.—Confirmation of positive presumptive tests may be carried out by transferring from positive tubes to tubes containing any of the liquid media listed in the preceding section. Transfers should be made as promptly as possible after gas appears in the primary tubes within the 48-hour period. Shake the tube gently and transfer a loopful to the confirmatory tube. The loop should have a diameter of not less than 3 mm. Incubate the inoculated tubes at a temperature of 37 degrees C. for a period of 48 hours.

Confirmation is positive if gas in any amount collects in the inner tube at any time during the incubation period. Completion of the test may be made on these tubes in the manner described for original tubes in section on analytical methods above. We have not sufficient experience in the routine use of liquid confirmatory media to express an opinion as to their relative merits when compared with confirmation on E.M.B. agar. Neither are we able to compare the several liquid media available for confirmation. It is desirable that this method be more fully tested in routine examination of water supplies.

MODIFICATION OF THE CITRATE TESTS.—(1) Simmons agar (Bacto dehydrated) may be employed to distinguish *B. coli* from *Citrobacter*. The agar is poured into sterile Petri plates. Inoculation is made from water suspensions as described above by streaking on the surface. Growth accompanied by change in color of the agar from green to blue denotes *Citrobacter*. If there is no growth *B. coli* are indicated.

(2) Peptone iron citrate agar appears to give similar differentiation. The medium is prepared by dissolving peptone—10 grams, potassium acid phosphate—0.25 gram, and ferric-ammonium-citrate —10 grams, in 1 liter of distilled water. Sterilize in small flasks or tubes. Plates are poured in the usual manner and inoculated on the surface. *Citrobacter* utilizes the citric acid radical and deposits iron. The growth becomes rusty red, while *B. coli* forms no such rusty deposit.

TESTS FOR OTHER INDICATOR ORGANISMS.—The colon group has generally been accepted as the most certain indicator of pollution. Some workers, however, have regarded other bacteria as of sufficient indicator significance to warrant testing for their presence in water.

Test for streptococci.—Prepare double-strength glucose broth (Bacto dehydrated), tube in 10-ml. portions and sterilize. Inoculate with an equal volume of the water to be tested. Incubate for 48 to 72 hours at 37 degrees C. Without shaking the tube, remove some of the material from the bottom by means of a pipette and spread out on a slide. Stain by Gram's method. Appearance of long chains of spherical cells constitutes a positive test. Finished water of high quality should not contain streptococci.

Test for anaerobes.—Various methods have been devised for this test. The most valuable appears to be plating appropriate volumes of water in sodium sulfate glucose iron agar prepared according to Wilson's formula. The medium may be prepared by adding 1.5 per cent of agar to peptone beef extract agar (Bacto dehydrated) and dissolving in the autoclave to form the agar base. When ready to perform the test, melt the agar base and add to each 100 ml. the following:

Iron chloride	1 ml. of an 8.1 per cent	aqueous	solution
Sodium sulfite	10 ml. of a 20 per cent	"	"
Glucose	5 ml. of a 20 per cent	"	"

The glucose should be dissolved in distilled water and sterilized in the usual manner. The sodium sulfite solution is made up fresh and steamed for 10 minutes without pressure. Iron chloride may precipitate if heated. It may be weighed out in a sterile dish and dissolved in sterile distilled water.

Plating is carried out by mixing equal volumes of the water and medium in a flask and pouring the mixture into large Petri dishes (diameter 150 mm.). If these are not available the mixture may be left in the flask. Since anaerobes are usually present as spores, it is permitted to warm the sample to about 50 degrees C. This facilitates mixing and has no harmful effect on the spores.

When the agar has solidified an equal volume of agar, cooled to about 50 degrees C., is poured over the bottom layer to serve as a seal and afford the anaerobic conditions necessary for growth. The sealing agar may be prepared by dissolving 2 per cent of agar in distilled water. The plates are incubated, upright, at 37 degrees C. for 24 to 48 hours, and examined for deep black colonies, which denote a positive test for anaerobes.

This test may be found of supplemental value in cases where positive presumptive tests do not confirm for the colon group. We do not regard it as in itself of sufficient value to warrant inclusion in the routine testing of water. Spores may, at times, resist the action of chlorine and appear in finished waters, thereby causing false positive presumptive tests. Their presence is readily detected by this method.

Summary of Colon Tests.—The routine tests for colon bacteria may be summarized briefly as follows:

(1) The determination of gas production in lactose broth resulting from the direct inoculation of water (presumptive test).

(2) The isolation on differential media, of typical coli colonies from tubes of fermented lactose broth (partially confirmed test).

(3) The identification of a Gram-negative, non-spore-forming aerobic organisms capable of producing gas when reinoculated.

DAILY ROUTINE PROCEDURE FOR BACTERIOLOGICAL EXAMINATION OF WATER.—The routine given below follows that suggested in "Standard Methods of Water Analysis," 1933 Edition. It will be of assistance to the water plant operator in systematizing his work.

First Day:

(1) Prepare dilutions as required.

(2) Make two agar plates from each dilution and incubate at 20 degrees C.

(3) Make two agar plates from each dilution, and incubate at 37 degrees C.

(4) Inoculate lactose broth fermentation tubes with appropriate amounts for coli-aerogenes group tests, inoculating two tubes with each amount.

Second Day:

(1) Count the agar plates made the first day and incubated at 37 degrees C.

(2) Record the number of lactose broth fermentation tubes which show 10 per cent or more of gas.

(3) Make an Endo or eosin methylene blue plate from the smallest portion of each sample showing gas. Incubate the plate at 37 degrees C.

Third Day:

(1) Count the plates made on the first day and incubated at 20 degrees C.

(2) Record the number of additional fermentation tubes which show 10 per cent or more of gas.

(3) Examine Endo or eosin-methylene blue plates. If typical colonies have developed, select one or more and transfer each to a lactose broth fermentation tube and an agar slant, both of which are to be incubated at 37 degrees C.

(4) If no typical colonies are found, incubate plates another 24 hours.

(5) Repeat procedure (3) of the second day, if tubes containing smaller portions of sample have shown gas.

Fourth Day:

(1) Select at least two colonies, whether typical or not, from the Endo or eosin-methylene blue plates which have been incubated an additional 24 hours; transfer each to a lactose broth fermentation tube and an agar slant, and complete the test as for typical colonies.

(2) Examine lactose broth fermentation tubes inoculated from plates on the previous day. Tubes in which gas has been formed may be discarded after the result has been recorded. Those in which no gas has formed should be incubated an additional 24 hours.

(3) Examine, microscopically, agar slants corresponding to lactose fermentation tubes inoculated from plate colonies and showing gas formation.

(4) Treat plates from procedure (5) third day as before.

Fifth Day:

(1) Examine lactose broth fermentation tubes reincubated the previous day.

(2) Continue examination of plates and cultures from procedure (4) fourth day.

Sixth Day:

(1) Examine lactose broth fermentation tubes and agar slants from procedure (2) fifth day.

INTERPRETATION OF RESULTS AND STANDARDS.—It is difficult to set an absolute standard to which all safe water must conform. A water which contains less than 100 bacteria per milliliter and causes no fermentation in lactose broth when five 10-ml. portions are tested is safe. The writer believes that with modern methods of purification such a standard may be required without undue hardship.

How far we may deviate from this standard and still maintain a sufficient margin of safety has long been a serious question. In cases where any of the five 10-ml. portions cause fermentation, due to colon bacteria, the number of tubes inoculated should be increased to 10 or 20. When such numbers are tested, no more than 10 per cent are permitted to be positive in the combined presumptive, confirmed, and completed tests, as outlined above. This would signifiy not more than one or two colon bacteria per 100 ml. of water. Experience has shown that such numbers may be tolerated with safety.

CHAPTER XVIII

REQUIREMENTS OF THE STATE DEPARTMENTS

BY J. N. HINYARD

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The purpose of this chapter is to outline briefly the requirements of various departments of the State of Texas as they concern the installation, operation, and maintenance of public water supplies—whether of the well or surface type—and also to enumerate some of the advantages of close cooperation with the various departments, particularly the State Health Department.

The various departments which will be concerned in one or more phases of water supply matters are the State Health Department, the State Fire Insurance Commission, and the Board of Water Engineers. Many difficulties may be eliminated and actual benefits derived by thoroughly understanding and conforming with the requirements of the above mentioned departments.

STATE HEALTH DEPARTMENT

The requirements of the State Health Department may be divided into two parts—those pertaining to installation, and those concerned with the operation and maintenance of the supply. The installation will be understood, for the purposes of this chapter, to include all planning, surveys, preparation of plans and specifications, and other pertinent phases, up through the actual physical installation.

INSTALLATION.—One of the functions of the State Health Department is to aid municipalities in the installation of water systems. Therefore the Department has certain requirements which must be fulfilled by the municipality. It is required that detailed plans of the improvement be submitted to the Department at least two weeks prior to the date on which its recommendations are asked. The plans shall include the following:

(1) A general map showing the main features of the system and indicating the relation of such features to each other and to the

district served. The map should indicate by suitable means the district to be served, impounding reservoirs, stream intakes, purification works, piping layout, pumping plants, canals, storage facilities, and other pertinent features.

(2) A map of the city or district to be served shall be presented. On this map shall be shown all streets, drawn to scale, with the accurate location of water mains, fire hydrants, and valves. Sizes and materials should be definitely shown. Other features, as pumping plants, reservoirs, etc., which fall within the confines of the map, should be shown with their elevations.

(3) Detailed plans of the source of supply shall be presented. These plans should include, in the case of a surface supply, dams, intake works, etc. A contour map of the area flooded by the reservoir, showing capacities at various depths, is required. In case of a ground water supply the area in which the well or wells are to be located should be suitably indicated on a drawing. A contour map of the area showing streams, sewers, and any other sanitary features which might affect the purity of the water, is required. Plans for the protective measures against pollution of proposed wells shall be shown. If possible logs of wells drilled in the near vicinity should be presented.

(4) A general plan showing pumping plants and location of principal pipe lines shall be submitted. The plan will show the capacity of the equipment, location of the pumping plants with reference to source of supply, and other consequential features. Detailed plans of reservoirs or tanks connected with the distribution system for storage or equalization of supply will be shown. These plans should show elevations, character of surrounding area, and any other features which might influence the reservoir or tank.

(5) Specifications and estimates of costs must cover all items and be complete in all respects.

(6) An engineer's report shall be submitted on letterhead size sheets, typewritten and firmly bound together. The scope of the report is indicated by the following headings:

(*a*) *Population studies.*—These will include a study of the character of the community, as well as an estimate of the growth, by five-year periods, until the available capacity is exceeded, or for a period of at least 30 years.

(*b*) *Consumption statistics.*—These must show total and per capita consumption as well as domestic and industrial uses and location of uses other than domestic. In proposed works estimates will be used.

(*c*) *General nature of development.*—A detailed description, correlated with the map, shall be given of the general nature of the supply, for example, lake, spring, wells, etc. A complete description of the principal works, as dams, pumping plants, purification works, etc., shall be given. The general character of the water and possible objections to its quality shall be indicated.

(*d*) *Surface waters.*—In case a surface supply is to be developed the characteristics of the watershed should be given. Such information as area, character, number of inhabitants, grazing, farming, industrial activities, etc., shall be covered in the report. Also, such sanitary features as sources of pollution, watershed protection, collection and diversion works, provisions for by-passing, shall be indicated. If possible, rainfall and stream flow statistics shall be presented.

(*e*) *Lakes and large reservoirs.*—Give data similar to (*d*) on important tributaries. Also give size, capacity, shore pollution, provisions for algae control, boating, intake arrangement and locations of same.

(*f*) *Wells.*—Indicate number, location, size and depth, log of well, date of drilling, type of casing, and protection against surface pollution. In this connection see recommended water well standards below.

(*g*) *Collecting tunnels and springs.*—Give location, and seasonal variation in output. Describe development of works and protection against pollution.

(*h*) *Reservoirs and basins.*—Give location, size, elevation, capacity, and area at various depths. Show inlet and outlet arrangements affecting efficient sedimentation. Describe baffling and drains.

(*i*) *Softening and filtration.*—Describe and locate principal works. Give method of treatment, kind, number and capacity of units used; chemicals used, expected dosage, and feeding arrangements. Describe reserve units, regulators, coagulating and mixing basins. Show disposition of effluent from sludge and wash drains. Describe clear water storage.

(*j*) *Disinfection.*—Give method used, type of apparatus, capacity of works, maximum and minimum feed of chemical, point of application, contact period before reaching consumer, fluctuation in water flow, and dose regulation method.

(*k*) *Pumping stations.*—Give type of equipment, capacity and range of capacity, power used, relative position in distribution system, and measuring devices used, as weirs, Venturi meters, etc.

(*l*) *By-pass arrangements which may result in the delivery of an inferior grade of water.*—In general by-passes around disinfection, purification or filtration plants will not be permitted.

(*m*) *Instructions.*—Instructions for operating any portion of the plant properly required of the designer, especially as relating to treatment and purification works. Indicate period of retainer for engineering supervision of operation. Submit estimate of operating cost with particular reference to amount and kind of attendance.

(*n*) *Distribution system.*—Show area, extent, location, and population supplied from each source of supply. Indicate single or dual system of distributors and inter-connections between systems. Show possibility of infection from exposed valves on non-domestic supply, if any. Indicate dead ends, show their necessity, provisions for flushing and blowing out. Show relative size of mains and blow-offs.

SANITARY STANDARDS FOR WATER WELLS.—Sanitary requirements for water wells are discussed in Chapter IV. Further details may be found in the bulletin, ''Water Well Standards,'' Texas State Department of Health, Austin, Texas.

DISTRIBUTION SYSTEM REQUIREMENTS.—(1) *Under-water crossings.*—The laying of pipe under water or under the bed of a stream should be avoided.

(2) *Valve chambers, air reliefs, and blow-offs.*—Chambers containing these appurtenances to the distribution system should not be connected directly to any sewer. In no case shall blow-offs be connected directly to a sewer.

(3) *Cross-connections.*—No connections or fixture, whereby polluting water can possibly get into the distribution system shall be allowed. Cross-connections are further discussed in Chapter VIII.

(4) *Dual systems.*—Dual systems should be avoided. In case it is necessary to deliver safe water to some other system which is unsafe, the delivery end of the safe water pipe should be installed at least 6 inches above the maximum water level in the unsafe water reservoir or receiver.

(5) *Water pipes and sewer pipes should not be laid in the same trench.*—Water lines should not be laid within 10 feet, measured horizontally, or 6 feet, measured vertically, of a sewer line. If this distance is not attainable the water line in all cases should be laid at a higher elevation. Where water and sewer lines must cross all that part of the sewer lying within 10 feet horizontally or 6 feet vertically from the water line should be of cast iron with leaded joints. Further discussion of laying mains and appurtenances will be found in Chapter VIII.

(6) *Hydrant drains.*—These should not be connected to storm or sanitary sewer, connect to gravel pocket, or drain to surface of ground.

OPERATION AND MAINTENANCE REQUIREMENTS.—The State Health Department has established definite requirements for the operation and maintenance of public water supplies, more particularly in connection with those features which affect safety. These requirements have been incorporated into a rating for the supplies. The score or rating which any supply attains is dependent upon the number of these requirements which are met in the operation and maintenance of the supply. After inspection the systems are rated as perfect, excellent, good, safe, fair, questionable, and unsatisfactory or unsafe. In grading a supply a maximum of 100 points is attainable. A penalty is inflicted for pollutional hazards around the supply or faults in operation. Credit is given for the adequate fulfillment of the requirements of the Department. Supplies are classified, for the purpose of rating, as ground water and surface water supplies. Details considered in grading follow.

Ground water supplies. The following are pollutional hazards which are considered as detrimental to the safety of a supply and should be avoided or eliminated.

(1) Habitations within 150 feet of the well.

(2) Cesspools, etc., within 150 feet of the well.

(3) Sewers within 50 feet.

(4) Improperly sealed or protected well tops.

(5) Leaky well casings.

(6) Flooding of the ground surface within 300 feet of the well by sewage-polluted surface water. Connections with polluted surface water.

(7) Open and unprotected reservoirs for treated or stored water. Contamination of pure-water reservoir with unsafe or

polluted water, as from raw water lines passing through clear-water basins.

(8) Failure to disinfect thoroughly all mains and appurtenances before installation.

(9) Defects in plant construction, as improper vents or manhole covers on clear wells. Cross-connections between the clear-water storage, or distribution system, whereby pollution may enter the system. No acceptable toilet facilities available at the plant. Inadequate storage or pressure.

The following are measures or factors which are protective in nature and influence the safety of the water. Wherever possible the protective measures should be adopted.

(1) Depth and kind of strata penetrated by well.—The strata range from the more to less desirable in the following order: (*a*) An impervious layer above the water-bearing stratum greater than 5 feet in thickness. (*b*) Sand over 20 feet deep with impervious overlaying strata. (*c*) Sand under 20 feet deep with impervious overlaying strata. (*d*) Sand and gravel over 25 feet in depth. (*e*) Sand and gravel under 25 feet in depth. (*f*) Seamy rock and limestone from screen to surface is undesirable. In all cases the well should be sealed and protected at the top. The wells should be fenced in to exclude all trespassers.

(2) Purification methods.—All of the methods of treatment, as storage, coagulation, sedimentation, filtration, disinfection, reduction of tastes and odors, which improve water quality are considered in the grading.

(3) Operation.—The responsible operator should hold an operator's certificate or license. A monthly operation report and bacteriological check record (two each) should be sent to the State Health Department. A certified laboratory should be maintained.

(4) Requirements as to quality.—Following are the conditions specified by the State Health Department. If the water fails to meet these standards a penalty is applied. (*a*) The turbidity shall not be over 10 parts per million, and preferably less than 5. (*b*) The water shall not have a color greater than 8 parts per million. (*c*) There shall be no odor or taste. (*d*) Total hardness shall not exceed 75 parts per million. (*e*) The water shall be of non-corrosive, with a pH between 7.5 and 9. (*f*) Sulfates shall be less than 50 parts per million. (*g*) Chlorides shall be less than

75 parts per million. (*h*) Absence of *B. coli* in 100 per cent of all 10-ml. inoculations.

Surface Supplies. The following conditions are considered in the grading of a surface supply:

(1) Certain features on the watershed of a surface supply are considered hazardous or undesirable and penalties are inflicted accordingly. (*a*) Population on watershed which might contribute to indirect pollution from the drainage area or direct pollution by sewage. (*b*) Highways, railroads, lumbering, camps, and animal pollution, when the population under (*a*) above is less than 75 per square mile. (*c*) Dump grounds or incinerators on watershed within a 20-mile zone of the reservoir or river intake. (*d*) Presence of industrial wastes, as salt in excess of 100 parts per million in average yearly minimum flow, and phenols in excess of 0.1 part per million in average minimum flow. (*e*) Leaky intake lines from a relatively unpolluted source passing through a sewage-polluted water. (*f*) Fishing, boating, swimming, picnicking, etc., on primary reservoirs or within one-half mile of the intake.

(2) Hazards connected with the distribution system are the same as those of a ground water supply.

(3) Protective measures which will add to the safety of the supply are: (*a*) proper watershed sanitary regulations, patrolling, enforcement, ownership of watershed by water authorities; (*b*) pre-chlorination, pre-filtration, and double coagulation; (*c*) coagulation and sedimentation; (*d*) duplicate equipment for chemical feed; (*e*) no short-circuits in basins; (*f*) filtration; (*g*) filters in good condition; (*h*) adequate control of equipment, gauges, etc., on filters, covered filters; (*i*) use of copper sulfate, aeration, ammoniation, activated carbon, and intake variation for taste and odor control; (*j*) adequate chlorine dosage and continuous operation of the chlorinator rather than intermittent dosage; (*k*) duplicate chlorinator or parts and ample supply of chlorine; (*l*) drains to pipe galleries and pump room floors; (*m*) mains and reservoirs flushed monthly; (*n*) essential equipment housed in fireproof buildings; (*o*) maintenance of a certified water laboratory; (*p*) certified operating personnel; (*q*) monthly operation and bacteriological test reports sent to the State Health Department.

(4) The same standards as to quality will prevail as with ground waters.

REQUIREMENTS OF THE STATE BOARD OF WATER ENGINEERS

The Board of Water Engineers is concerned principally with the installation phase of the development of a public water supply. The engineers on this board should be consulted before attempting any major water supply improvement. Their requirements are rigid and must be fully complied with.

WELLS OR UNDERGROUND WATER.—(1) An artesian well is defined as an artificial well in which, if the well is properly cased, the water will rise by natural pressure higher than the first impervious stratum above the water-bearing formation. Artesian wells shall be tightly cased and furnished with such mechanical appliances as will prevent the flow and waste of the water over the surface of the ground around the well or wasting from the well into a stratum through which the well passes. Water from an artesian well shall not be permitted to waste into any river, creek, or other surface stream, sewer, street, road, etc., or upon the land of any person or party other than the owner. It may, however, be used for proper irrigation on or off the land of the owner.

(2) All water wells, drilled or dug, which encounter salt water or a water of such a character that it will be injurious to vegetation or to another water-bearing stratum shall be securely plugged or cased to prevent the escape of the mineralized water over the surface or into any strata carrying potable water. This plugging or casing shall be carried out by the well owner and within 30 days from the date of having been ordered to do so.

(3) Any person boring an artesian well shall keep a complete and accurate record of the depth, thickness, and character of the different strata penetrated, and shall, on completion of the well, send a copy of the log of the well to the Board of Water Engineers. Within one year from the date of developing an artesian well the owner or operator thereof shall make a test measurement of the well and furnish a sworn statement to the Board showing the quantity of water supplied by the well, and a declaration of the use or uses to which the water is being devoted.

(4) Before any defective well is recased or plugged an application for a permit shall be filed, by the owner or his duly authorized representative, with the Board. The application shall give as complete information as possible in regard to name and address of owner of well, location of well, depth, size and amount and

location of casing in the well, distance below the surface to the water in the well, strata penetrated, distance down to top of any salt-water stratum and thickness of said stratum. It shall give the proposed method of plugging of well as well as any other pertinent data. The Board upon its own intiative may, after the examination of a well, order such corrective steps as are necessary to cure the faults of the well. Upon completion of the recasing or plugging the engineer or person who does the work shall file with the Board of Water Engineers a sworn statement outlining in detail the manner in which the work was done. This statement shall be filed within 30 days after completion of the work. The work shall be then inspected by the Board, and any additional work that should be done will be specified.

(5) The permissible methods of constructing a well, particularly to prevent pollution of potable waters by salt water, are as follows:

(*a*) If in the construction of a well salt water is encountered in a stratum that lies above the fresh water stratum, the well shall be cased completely from the surface down to the bottom of the salt stratum, or deeper if necessary. The casing shall be sealed securely and in such a manner as to prevent the entrance of salt into the fresh-water stratum. In case salt water is encountered the casing shall be of pipe of not less than the approved standard weight. See Chapter IV.

It is advised that in case a salt-water stratum is penetrated in the course of drilling, a mud-laden fluid be used in the hole during the drilling operation to seal off the stratum and to minimize corrosion of the well casing.

(*b*) If salt water is encountered below the fresh-water stratum the proper procedure is as follows: 1. Where the salt water is not under a pressure sufficient to raise it above the level to which the water in the fresh-water stratum will rise, the salt water shall be cut off by first filling the hole to a level within a few feet of the bottom of the fresh-water stratum with a mud-laden fluid (weighing not less than 10 pounds to the gallon) and bridging and cementing the hole up to the bottom of the fresh-water stratum. 2. Where the salt water is under pressure sufficient to raise it above the level to which the water in the fresh-water stratum will rise the Board requires that the salt water be cut off by plugging with a suitable material, as lead wool, lathe turnings or burned wire cable and soft rope. The plug shall be solidly tamped in and shall extend from the bottom of the well to the top of the salt-bearing stratum. If the shut-off is proved successful by tests the plug is capped with cement.

(6) Permissible methods of repairing wells that encounter salt water are as follows:

(*a*) A defective well in which the salt-water stratum lies above the fresh-water stratum shall be recased either by withdrawing the old casing and replacing it with new casing of like diameter, or by inserting a new casing of smaller diameter into the old casing. In both cases the specified weight of casing shall be used and it shall be so sealed as to eliminate the salt water.

(*b*) In a defective well where the salt-water stratum lies below the fresh water, repairs shall be made as in (*b*) of (5) above.

(7) Permissible practice for abandoning wells that encounter salt water. Before the well is abandoned it shall be plugged in the following manner: The well, if practicable, shall be opened to the bottom of the original hole and shall be filled with a heavy mud-laden fluid by pumping and circulating the fluid, or by means of a dump bailer. If the well cannot be opened to the original depth the fluid shall be pumped in under pressure. After the well has been filled from the bottom to the top with the fluid it shall be bridged at some point between the salt- and fresh-water strata and the bridge capped with a cement plug if necessary.

SURFACE WATERS.—The surface waters of the State are declared to be the property of the State and use of them may be acquired by appropriation for various uses, including domestic water supply. Any person or municipality desiring to so use surface water, by storage or diversion, shall make application to the Board for a permit for such storage or diversion. The application shall be in writing and sworn to; shall set forth the name of the municipality or person making application; nature and purpose of proposed use; location and description of proposed works; time within which it is proposed to begin construction; time required for the application of the water to the proposed works, pumping plants, dams, etc. It shall show the course of the river or stream, position and area of all lakes and reservoirs intended to be used or created. The point where surplus water is to be returned to the stream must be shown. Detailed plans for any dams which will be over 6 feet high when completed shall be presented for approval. The

State Board of Water Engineers shall fix the time when actual construction work shall be commenced on any proposed project. This time shall not exceed 2 years from the date of the issuance of the permit. A permit is not required for any alteration or enlargement where the proposed work will not result in an increase in the amount of water diverted. However, a detailed statement and plan for such changes shall be filed with the Board.

Within 30 days, unless otherwise specified by the Board, the applicant shall begin actual construction of the proposed improvement and shall prosecute the work continuously and diligently to completion. If work is not so executed the Board, may, after a 30 days notice to applicant, cancel the permit.

When a permit is issued the claimant's right to use such water dates from the date of filing the application. Rights to the use of water acquired shall extend only when beneficially used for purposes stated in the application. Any appropriation which is willfully abandoned during any 3 successive years shall be forfeited.

The point of diversion shall not be changed without a permit. Also a permit must be obtained before effecting any improvement or alteration which will result in the use of more water than granted by the permit. In no case shall there be placed an obstruction of any kind in the bed of any river which will result in changing the bed of such river. No intake or channel shall be cut or dug into the stream without a permit.

Within 10 days after the expiration of 3 years from the date fixed by the terms of the permit to the municipality, said municipality shall file with the Board an affidavit stating the volume of water which has been put to beneficial use at the expiration of the 3 years and stating specifically the manner of such use. During January of each year the Board will furnish to each appropriator a blank form. Upon this he will record the quantity of water used during the preceding calendar year, the use made of same and the source of supply. These reports must be sworn to and mailed to the Board not later than the first day of March of each year.

REQUIREMENTS OF THE STATE FIRE INSURANCE COMMISSION

One of the chief functions of the State Fire Insurance Commission is to set the fire insurance key rate for the cities and towns of Texas. The Commission has established definite regulations and requirements which should be complied with in order to insure the maximum fire protection and to secure for the city as low a key rate as possible. The key rate has been defined as a measure of the ability of the city to fight fire, and a measure of the fire hazard in the municipality. This rate may be any amount up to and including one dollar per $100 of insurance. It depends upon the number of requirements met by the municipality. There are several items which are considered in arriving at a key rate for a city. One of these items is the water works system. This, of course, includes source of supply, the plant, distribution system, and appurtenances.

WATER AVAILABLE.—The quantity of water available is most important from the standpoint of fire protection. The amount of water which shall be available for standard fire protection requirements is 110 gallons per capita per 24 hours. The supply may be obtained from a well, group of wells, springs, lake or river. Where lakes and rivers are used as supplies the deficiency in rainfall is a factor and is considered from the insurance standpoint. With an underground supply it is necessary to provide storage facilities at the ground level with a minimum of 30,000 gallons capacity. In larger cities this capacity must be increased according to the size of the city. If the supply is deficient on the 110-gallon basis the penalty may be avoided by the installation of a proper amount of storage, i.e., 12 hours supply at the 110-gallon rate, in the reservoir and to be retained for fire purposes only. It shall be arranged with proper separate gated suction lines. The ground-level storage is not to be confused with the elevated tank.

PUMPING EQUIPMENT.—There shall be a minimum of two pumping units, each having a capacity of 500 gallons per minute, together with all the necessary auxiliary equipment, also to be provided in duplicate. Pumping units of smaller capacity may be combined to make up one of the 500-gallon units but the other unit shall not be less than the stated capacity. All pumping equipment shall be capable of making its rated capacity against a pressure of not less than 60 pounds per square inch at any fire hydrant in the mercantile district.

The standard of source of power for operating the pumping equipment and auxiliaries is steam or water power, as these are considered the most reliable. Electric power, to be accepted without penalty, must be from a reliable source and available from two or more separate circuits; all switching facilities must be in duplicate; and all wiring must be in accordance with the National Electric Code. Units driven by oil engines may be acceptable with qualifications. Such units of over 50-horsepower capacity are considered more reliable than units of smaller size.

THE DISTRIBUTING SYSTEM.—All distribution mains must be of cast iron of either the sand-cast or other approved type.* The use of other materials means the application of a 5 cent penalty. Mains shall be not less than 8 inches in size in the business district or less than 6 inches in size in the residential sections. The use of 4-inch pipe in fire protection systems is not recommended and its use has meant the application of deficiency penalties in the various key rates.

All fire hydrants to be used in the future in public fire protection systems shall be of the three-way type with a minimum valve opening of 5 inches and it is urged that separate gate valves be provided for each hydrant lead. The distribution of the fire hydrants shall be such that in the mercantile and industrial sections there shall be a hydrant at each street intersection in front, as well as rear, of the business block, and in the residential sections they shall be placed approximately 600 feet apart. In order to insure the proper operation of all fire hydrants they must be oiled, greased, and flushed every ninety days and they must be painted a distinctive color at least once each year.

For recommendation from a fire protection standpoint, a minimum size of elevated tank is 50,000 gallons, to be installed on a tower 100 feet high to the bottom of the tank. Where the population of a city or town requires a capacity larger than 50,000 gallons, this required capacity may be arrived at by calculating the amount of water necessary for the size of the city, based upon 110 gallons per capita for 24 hours, and then taking 10/24 of this amount. Advantage may be taken of natural elevation, if it is sufficient in height. Supply mains delivering water to the center of the distribution system shall be at least 8 inches in size, or larger where the requirements demand, and they shall be in duplicate from the pumping station to the center of the distribution system and to the bottom of the riser of the elevated tank or reservoir.

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* Transite pipe, when manufactured and installed according to the specifications of the National Board of Fire Underwriters, may be used without penalty.

All pumping equipment must be housed in a brick, stone, or reinforced-concrete pumping station with a non-combustible roof. This roof may be of the wooden deck type. The same building requirements regarding generating equipment are necessary.

In the pumping station all piping shall be arranged with long-turn fittings and the pumps shall take suction from a common header and discharge into a common header which is connected in duplicate with the underground distribution main.

IMPORTANCE OF COOPERATION WITH THE STATE FIRE INSURANCE DEPARTMENT.—Every water works superintendent should be interested in reducing the fire hazard of his city as well as in securing a lowering of the fire insurance key rate. A small reduction here will mean a large saving to the property owners of the city. Frequently the expenditure of only a few dollars will gain a considerable reduction. The State Fire Insurance Department is very willing to render any assistance possible, from a fire protection standpoint, in an improvement program. It is recommended that the Department be consulted before making any changes or improvements in order that the maximum saving to the municipality be obtained.

Chapter XIX

LICENSING OF WATER PLANT OPERATORS

By W. T. Gooch

Head, Chemistry Department, Baylor University, Waco, Texas

Improvements in water purification have been of untold benefit in health and sanitation during the years. These improvements have kept pace with the developments in medicine, surgery, and public health generally, and are no less important. Studies of death rates show a decrease with each outstanding improvement in water purification. The physicians who guard our health may not practice their profession without thorough preliminary training and a license issued by the state. It is equally important that the men who have charge of our water supplies, and who are directly responsible for our health in that capacity, should be properly trained and also certified through some method of licensing. Accordingly, the Texas Water Works Short School, at Temple, Texas, in 1933, initiated a voluntary system of licensing operators of water plants and superintendents of water systems.

The voluntary licensing system for water plant operators was initiated with the following purposes in view: (1) to promote public health by keeping trained, efficient, and capable men in charge of water plants as a precaution to insure a supply of safe and potable water at all times; (2) to give the trained and experienced operators a defense against untrained job seekers, local or imported; against political favorites who seek office with each change of administration; and against untrained and inexperienced men seeking to displace qualified operators and superintendents; (3) to furnish a method of measuring the qualifications and abilities of water superintendents and operators and thus tend to make their positions more permanent.

The system as now operated provides for three grades of licenses: A, B, C. Each grade is obtainable by superintendents, operators or others in responsible charge of a water supply, and whether the supply is either well or surface. Laborers around a plant, clerks in the office, repair men on the distribution system, or others not directly employed in the production of water are not eligible for license.

The three grades of licenses are different as to the qualifications and requirements which must be satisfied. All water supply operators and others eligible must apply first for the Grade C license. To obtain this, the applicant must be employed in the water works profession when applying, and he must meet the following qualifications:

(1) One year of operating experience.
(2) A general understanding of water supply protection, potential health hazards, the standards for safe and potable drinking water, both bacteriological and chemical, and the practice of water plant operation.

Separate examinations are given to operators of well and surface supplies. These examinations can be taken in the applicant's home town, in the office of the mayor, city manager, or under the supervision of a city councilman, one of whom must be present during the examination. The applicant may take with him to the examination and use any notes he may wish, but he may not obtain aid from any other source. He must write out the answers in the presence of the official supervising the examination. The answers should be full enough to show the applicant's knowledge to the best advantage, but should not be too voluminous.

Before the examination questions are sent to the official who is to conduct the examination, the operator must fill out and send in a sworn statement of his qualifications, covering present position, experience, etc., as outlined on the form given in Appendix A of this Manual. The application is checked by the Chairman of the Advisory Committee, and if it is found to be satisfactory he authorizes the Secretary of the Texas Water Works Short School to send the questions. When these are answered and certified the examination paper must be sent to the Chairman of the Licensing Committee, who grades the papers and asks the members of the committee to authorize the issuance of the license.

To qualify for the Grade B license the applicant must show that he has a general knowledge of the subjects listed below, in addition to 3 years of operating experience. By ''general knowledge'' is meant a working familiarity with the problems encountered under those items and the ability to handle in a practical way the details of operation and management that might occur. It is not intended that such questions would be asked in this examination as would be asked of a person qualifying for a college degree. The questions are much more comprehensive, however, than those asked in the Grade C examination. The requirements are:

I. Well-supply operators:
    1. Three years operating experience.
    2. A general knowledge of:
        a. Well construction.
        b. Pump mechanics of ground waters.
        c. Geology and hydraulics of ground waters.
        d. Water biology including bacteriology and algology.
        e. Chlorination and disinfection.
II. Surface-supply operators:
    1. Three years operating experience.
    2. A general knowledge of:
        a. Water treatment, including softening, coagulation, chlorination, filtration, and taste control.
        b. Water chemistry and corrosion control.
        c. Water biology, including bacteriology and algology.
        d. Pump mechanics and recording.
        e. Reservoir sanitation control.

To illustrate what is meant by the above it may be stated that the Grade B well-supply operator is expected to know usual practice in the types of casing used, general methods of well drilling, methods of sealing the casing to prevent pollution from the ground, advantages of various types of screens, measures of resistance to corrosive conditions.

The applicant for the Grade B surface-supply license, under the heading of water biology, should be familiar with the usefulness of bacterial test methods, the purpose and methods of making algae determinations, the meaning of *B. coli* in the water supply, and in a general way, the purpose and method of making the test.

To qualify for the Grade A license the applicant must show 5 years of experience and must pass an examination more rigorous than that given to Grade B applicants. The information required, covers the same ground but must be more specific. The questions are arranged so that certain options may be selected by a superintendent, by a chemist-bacteriologist in control of a water purification plant, or by the operator of a well supply or of a surface supply. Sufficient questions are given in each of the fields named above for the applicant to be examined thoroughly as to his qualification for the license.

Examinations for Grade B and Grade A licenses are given at the close of each Water Works Short School and at such other times and places as the Licensing Committee may decide. No notes or other aid may be used in taking these examinations. They must be written by the applicant in the presence of some member of the Licensing Committee.

The Grade A license is perpetual; Grade B expires after five years, and Grade C expires after three years. At present the licenses may be renewed by reexamination, although it is strongly recommended that each reexamination be for a higher grade. It is probable that some limitation may be set in the future as to the number of times a license of the same grade may be renewed. Provisions as to renewal were included to encourage operators to keep abreast of the advances in their profession and to stimulate in general the alert and progressive attitude which is necessary to obtain and maintain a water supply that is safe at all times.

In order to pay the cost of issuing the licenses, stamps, seals, etc., the applicant may donate an amount of one dollar to the Short School after he is notified that he has passed the examination. This fee is used to defray the cost of printing and postage, and must be sent to the Treasurer, Texas Water Works Short School, Capitol Station, Austin, Texas. No charge is made for the licensing or for the examination.

As already indicated the form of application used is given in Appendix A. The applicant or prospective applicant may prepare himself for the examination by study of the portions of this Manual that cover the subjects for which he will be held responsible. Men who are preparing for the A and B Grade examinations may find it both profitable and interesting to consult some of the references which are also given in the Manual.

APPENDIX A

APPLICATION
FOR
WATER SUPPLY OPERATOR'S LICENSE

State Department of Health
and
Advisory Licensing Committee,
Austin, Texas.
Dear Sirs:

I herewith apply for grade..water
(*A*, *B*, or *C*, Well or Surface Supply)
supply operator's license. I list the following qualifying data as correct to the best of my knowledge:

1. Name in full..
(Print name plainly)
2. Present post office address..
3. Present occupation..
4. Previous experience in water supply work..
(State fully your experience
....
and the time that you have been employed in water works engineering,
....
supervision, analytical operation or installation work)
5. List further qualifications relating to water supply control; such as grade or high school education, graduate technical courses, vocational training, mechanical or electrical ability, number of Texas Water Works Short Schools attended, etc.
....
....

NOTARY PUBLIC
Sworn to and subscribed before me
by the above-named party this........
day of..................................193........

....
Notary Public in and for
..................................County, Texas.

Signed:

Date:..

Place:..

No fee is charged for this application nor for the examination. When the license is issued a $1.00 charge is made partially to cover expense of printing and mailing.

APPENDIX B

SOURCES OF STANDARD SPECIFICATIONS FOR WATER WORKS MATERIALS

1. Sand Cast Pipe and Special Castings. Adopted by the American Water Works Association 1908. "Water Works Practice," * pages 650–688.
2. Centrifugally Cast Pipe. Specifications of U. S. Bureau of Standards. W.W.P. 421.
3. Hydrants and Valves. Adopted by the American Water Works Association in 1913, revised 1916. "Water Works Practice," * pages 689–699.
4. Cold Water Meters—Disk Type. Adopted by the American Water Works Association in 1921. "Water Works Practice," * pages 700–706.
5. Pig Lead for Jointing. Specification B 29–35. American Society for Testing Materials,† 1935.
6. Cotton Rubber-Lined Fire Hose for Public and Private Fire Department Use. Specification D 296–35. American Society for Testing Materials.†
7. Chemicals Used in Water Purification:
    - Alum. "Water Works Practice," * page 707.
    - Lime. This Manual, page 116.
    - Hydrated lime. "Water Works Practice," * page 708. This Manual, page 116.
    - Quicklime. "Water Works Practice," * page 708. This Manual, page 116.
    - Liquid chlorine. "Water Works Practice," * page 709.
    - Chloride of lime. "Water Works Practice," * page 709.
    - Sulfate of iron (ferrous sulfate) (copperas). "Water Works Practice," * page 709.
    - Soda ash (sodium carbonate). "Water Works Practice," * page 708.
    - Copper sulfate (bluestone). "Water Works Practice," * page 710.
    - Ammonia.
        - Anhydrous. None.
        - Ammonium sulfate. None. Suggested: Material shall contain not less than 25 per cent ammonia (NH_3), no traces of cyanide, no traces of pyridine, and not more than 0.15 per cent moisture.
        - Ammonium chloride. None.
    - Activated carbon. None. American Water Works Committee has made recommendations but no official action has been taken. Suggested specifications are:
        - Phenol adsorption capacity—25 parts per million shall reduce phenol in a solution containing 0.1 part per million to 0.01 part per million when stirred for 2 hours.
        - Ash—shall not exceed 15 per cent by weight.
        - Moisture—shall not exceed 5 per cent by weight.
        - Fineness—100 per cent shall pass a 100-mesh sieve and 95 per cent shall pass a 200-mesh sieve.

* See Appendix D, for publishers of this book.

† Obtainable from the American Society for Testing Materials, 206 South Broad Street, Philadelphia, Penn.

APPENDIX C

LABORATORY EQUIPMENT, SUPPLIES, AND STANDARD SOLUTIONS

BY CLYDE C. HAYS

City Chemist and Bacteriologist, Waco, Texas

CHEMICAL EQUIPMENT AND SUPPLIES

A. For control of water plants with chlorine treatment only.

Apparatus	*Number*
Bottles, glass-stoppered, 32 oz.	6
Bottles, glass-stoppered, 16 oz.	6
Pipettes, 1 ml.	6
Color disk—chlorine, Hellige No. B	1
Color comparator for disk, pocket model	1
Reagents	
Orthotolidin solution for residual chlorine test	32 oz.

B. For control of water plants having softening, coagulation, filtration, and chlorination treatment.

Apparatus	*Number*
Analytical balance	1
Balance weights (set)	1
Trip scales	1
Scale weights (set)	1
Drying oven	1
Hydrogen ion apparatus	1
Nitrogen distillation apparatus	1
Beakers, 2 liter	12
Beakers, 1 liter	12
Beakers, 600 ml.	12
Beakers, 400 ml.	12
Beakers, 250 ml.	12
Beakers, 100 ml.	12
Watch glasses, 75 mm.	12
Bottles, glass-stoppered, 32 oz.	36
Bottles, glass-stoppered, 16 oz.	12
Bottles, glass-stoppered, 8 oz.	12
Wash bottles, 1 liter	8
Burettes, 50 ml.	12
Burners, Meeker	2
Burners, Bunsen	6
Clamps, burette	6
Clamps, condenser	2
Clamps, holders	6
Clamps, pinch	12
Nessler tubes, 100 ml.	24

Apparatus	*Number*
Condenser	1
Corks, bags, assorted sizes	6
Cork borers	1
Crucibles, 46 mm.	12
Crucibles, Gooch, 25 ml.	12
Graduated cylinders, 1 liter	4
Graduated cylinders, 100 ml.	6
Graduated cylinders, 25 ml.	4
Graduated cylinders, 10 ml.	4
Desiccators, 250 mm.	3
Evaporating dishes, 75 mm.	12
Evaporating dishes, 90 mm.	6
Files	2
Filter paper, 9 cm., packages	12
Filter paper, 12 cm., packages	2
Filter paper, quantitative, 9 cm.	2
Erlenmeyer flasks, 500 ml.	24
Erlenmeyer flasks, 300 ml.	24
Volumetric flasks, 1 liter	6
Volumetric flasks, 500 ml.	2
Volumetric flasks, 250 ml.	6
Volumetric flasks, 200 ml.	12
Volumetric flasks, 100 ml.	12
Funnels, 65 mm.	12
Funnels, 90 mm.	2
Funnels, Buechner, 80 mm.	2
Glass tubing, 7 mm., lbs.	10
Kjeldahl flasks, 500 ml.	6
Kjeldahl flasks, bulbs	6
Pipettes, 100 ml.	6
Pipettes, 50 ml.	6
Pipettes, 25 ml.	6
Pipettes, 10 ml.	6
Pipettes, 5 ml.	6
Pipettes, 1 ml.	12
Pipettes, graduated 1/10, 10 ml.	6
Pipettes, graduated 1/10, 5 ml.	6
Rings, iron, 4 inch	4
Rings, iron, 3 inch	6
Spatulas, 3 inch	2
Iron supports	6
Thermometers, 10 to 110° C.	4
Thermometers, 0 to 250° C.	2
Crucible tongs	6
Wire gauze, 4 inch	12
Triangles, 2 inch	12
Rubber tubing, $\frac{1}{4}$ inch (ft.)	50

Apparatus	*Number*
Rubber stoppers, assorted (lbs.)	10
Desiccator plates, 230 mm.	3
Water suction pumps	1
Glass rods, 6 mm. (lbs.)	2
Soxhlett flask, 150 ml.	1
Tripods	2
Evaporating dishes, platinum	2
Water bath, 6 openings	1
Platinum tipped tongs	1
Dropping bottles, 60 ml.	6
Burette support	2
Funnel support	1
Test tube support	1
Test tube brush	3
Jar brush	2
Turbidimeter, Jackson	1
Mortar and pestle	1

Supplies	*Quantity* (pounds)
Sulfuric acid, C. P.	27
Sulfuric acid, Tech.	18
Potassium dichromate, Tech.	10
Sodium carbonate, anhydrous	1
Phenolphthalein	50 (grams)
Methyl orange	50 (grams)
Sodium hydroxide	10 (sticks)
Hydrochloric acid, C.P.	12
Sodium thiosulfate crystals	1
Ammonium carbonate	½
Chloroform	½
Potassium iodide	2
Starch, corn	1
Potassium permanganate	1
Ammonium oxalate crystals	1
Alcohol, grain	1 (quart)
Castile soap powder	1
Ammonium hydroxide	8
Calcium carbonate, C.P.	1
Calcium hydroxide, C.P.	1
Hydroxylamine hydrochloride	¼
Benzidine hydrochloride	¼
Potassium chromate, C.P.	¼
Silver nitrate, C.P.	¼
Sodium chloride, C.P.	1
Aluminum sulfate crystals	1
Bromine	¼
Ammonium chloride	1
Disodium phosphate	1

Supplies	*Quantity* (pounds)
Barium chloride	1
Barium hydroxide	1
Potassium chloroplatinate	1 (gram)
Cobaltous chloride	$\frac{1}{4}$
Ferrous ammonium sulfate	$\frac{1}{2}$
Potassium thiocyanate	$\frac{1}{2}$
Manganous sulfate crystals	1
Nitric acid, C.P.	6
Alizarine red, S.	10 (grams)
Sodium bicarbonate	1
Fuller's earth	1
Glass wool	1
Orthotolidin	25 (grams)
Sodium hypochlorite	4 (ounces)
Litmus paper	4 (vials)

STANDARD SOLUTIONS

COLOR TEST SOLUTIONS.

Dissolve 1.245 grams of potassium chloroplatinate containing 0.5 gram of platinum and 1 gram of crystallized cobaltous chloride containing about 0.248 grams of cobalt, in water with 100 ml. of concentrated hydrochloric acid, and dilute to 1 liter with distilled water. This solution has a color of 500.

To prepare standards having colors of 5, 10, 15, 20, 25, 30, 35, 40, 50, 60, 70, dilute 0.5, 1, 1.5, ml., etc., of the above solution to 50 ml. in standard Nessler tubes.

SOLUTIONS FOR HARDNESS, SOAP METHOD.

1. Make up a stock soap solution by shaking 100 grams of pure powdered castile soap with 1 liter of 80 per cent grain alcohol, let stand overnight and decant.

2. Prepare standard calcium carbonate solution by dissolving 0.5 gram of calcium carbonate in about 5 ml. of 1 to 3 hydrochloric acid. Add about 40 ml. of boiled and cooled distilled water and add ammonium hydroxide until slightly alkaline to litmus. Make up to exactly 500 ml. with boiled and cooled distilled water. Then 1 ml. = 1 milligram of $CaCO_3$.

3. Determine the lather factor by adding the soap solution drop by drop from a burette to a 50-ml. portion of distilled water contained in an 8-ounce glass-stoppered bottle, shaking between the additions. When sufficient soap solution has been added to produce a lather which remains over the entire surface of the water for 5 minutes (bottle should be laid on its side) record the milliliters of solution added. This is the lather factor.

4. Pipette 25 ml. of the standard calcium carbonate solution into a bottle. Add 25 ml. of boiled distilled water and titrate with soap solution as above, recording the milliliters used to produce a permanent lather.

Adjust the soap solution so that 1 ml. equals 1 ml. of standard calcium carbonate solution. This is done by calculating the milliliters of soap solution necessary to make 1 liter of required solution, using the formula: (Milliliters of soap solution Step 4 − lather factor) × 40 = milliliters of stock soap solution required.

Dilute this quantity of stock solution to 1 liter with 80 per cent alcohol. 1 ml. = 1 milligram of calcium carbonate.

RESIDUAL CHLORINE. ORTHOTOLIDIN METHOD.

(*A*) *Orthotolidin solution.*

1. Weigh out 1 gram of orthotolidin, transfer to a 6-inch mortar, and add 5 ml. of a 1 to 5 dilution of hydrochloric acid (previously prepared by adding 100 ml. of concentrated hydrochloric acid, Sp. Gr. 1.18–1.19, to 400 ml. of distilled water). Grind to a thin paste.
2. Add to the paste 150 to 200 ml. of distilled water. The orthotolidin goes into solution immediately.
3. Transfer to a 1000-ml. graduate and make up to 505 ml. with distilled water.
4. Make up to the 1000 ml. mark by adding the balance (495 ml.) of the 1 to 5 hydrochloric acid.

(*B*) *Copper sulfate solution.* Dissolve 1.5 grams of copper sulfate and 1 ml. of concentrated sulfuric acid in distilled water and make up to 100 ml.

(*C*) *Potassium dichromate solution.* Dissolve 0.25 gram of potassium and 1.0 ml. of concentrated sulfuric acid in distilled water and make up to 1 liter.

(*D*) *Preparation of color standards.* Mix the quantities of copper sulfate and potassium dichromate as given in Table XXII in 100-ml. Nessler tubes having the graduation mark 300 millimeters from the bottom. Dilute with distilled water to the 100-milliliter mark.

TABLE XXII.—PREPARATION OF PERMANENT STANDARDS FOR CHLORINE CONTENT

Chlorine	Solution of copper sulfate	Solution of potassium dichromate
Parts per million	ml.	ml.
.10	1.8	10.0
.20	1.9	20.0
.25	1.9	25.0
.30	1.9	30.0
.35	1.9	34.0
.40	2.0	38.0
.50	2.0	45.0

N/50 Sulphuric Acid.

Weigh out exactly 5.3 grams of chemically pure sodium bicarbonate which has been heated for 30 minutes and allowed to cool. Dissolve in 1000 ml. of water without agitation. This is N/10 sodium carbonate solution.

Measure 200 ml. of the N/10 sodium carbonate and make up to 1 liter, which now becomes N/50 sodium carbonate solution.

Prepare the N/50 sulfuric acid solution by measuring exactly 1 ml. of chemically pure sulfuric acid into 1 liter of distilled water. Insert stopper in graduate and shake thoroughly. Measure 50 ml. of the N/50 sodium carbonate with a graduated pipette, heat to boiling and titrate with the sulfuric acid solution, using methyl orange as an indicator. Calculate the dilution so that equal volumes of the acid solution and carbonate solution neutralize each other.

Example: If 50 ml. of the carbonate solution required 48 ml. of the acid solution, each 48 ml. of the acid must be diluted to 50 ml., or the whole of the remaining acid in the same proportion.

Calculation: X = Number of milliliters of water to be added to 1000 ml.
48 = Average of titrations in milliliters.
$X = 20\ (50 - 48)$
X = 40 ml. of water to be added to one liter, to make solution exactly N/50 normal.

N/44 Sodium Hydroxide Solution.

First prepare a normal sodium hydroxide solution by dissolving exactly 40 grams of chemically pure sodium hydroxide in 1 liter of water, and checking against a normal acid solution.

Now withdraw exactly 23.7 ml. of the normal sodium hydroxide solution and dilute to exactly 1 liter with boiled cooled distilled water. (Note: The above solution will not be exactly N/44, but it will be close enough for all practical purposes in water work.)

Bacteriological Equipment and Supplies

(Compiled by I. M. Lewis, Dept. of Botany,
University of Texas)

Apparatus (Central Scientific Company Catalog)	*Number*
No. 48240 sterilizing oven, 24 × 14 × 18 inches (gas)	1
No. 46060 incubator 26 × 18 × 18 inches (electric)	1
No. 44120 autoclave 11 × 24 inches (gas)	1
No. 61050 microscope (monocular, Bausch and Lomb No. 1 & 8)	1
No. 44370 Petri dishes, "Pyrex" 100 × 15 mm.	50
No. 16120 Cylinders—100 ml.—graduated	3
No. 16120 Cylinders—500 ml.—graduated	3
No. 16120 Cylinders—1000 ml.—graduated	2
No. 46640 pipettes, Exax Blue Line, Capacity 1 ml. in 1/10 ml.	30
No. 46640 pipettes, capacity 10 ml. in 1/10 ml.	30
No. 46670 pipette boxes, copper, $2\frac{1}{2} \times 16$ inches	2
No. 48520 test baskets 6 × 6 × 6 inches	6
No. 44500 culture tubes—$7 \times \frac{7}{8}$ inches	1 gross
No. 44500 culture tubes, size C, $3 \times \frac{3}{8}$ inches	1 "
No. 44500 culture tubes, size J, $6 \times \frac{3}{4}$ inches	1 "
No. 44500 culture tubes, size A, $2 \times \frac{1}{4}$ inches	1 "
No. 19255 thermometers, 0–110° C.	2
No. 19255 thermometer, 10–205° C.	1
No. 19205 test tube supports, size B	2

Apparatus (Central Scientific Company Catalog)	*Number*
No. 46220 inoculating needle holders	2
No. 46210 inoculating needles, size A	1 pkg.
No. 46210 inoculating needles, size B	1 pkg.
No. 18755 spatula, stainless steel, size D	1
No. 18775 spoon, horn, size C	1
No. 44320 counting plate	1
No. 60400 reading glass, 2 × 3 × ⅞	1
No. 14015 glass marking pencils, wax No. c	6
No. 2640 balance, Cenco Triple Beam	1
No. 14905 flasks, "Pyrex" Brand, 500 ml	12
No. 14905 flasks, "Pyrex" Brand, 1000 ml	2
No. 14905 flasks, "Pyrex" Brand, 250 ml	24
No. 10351 bottles with black screw caps, 4 oz	24
No. 10351 bottles with black screw caps, 8 oz	24
No. 10415 screw caps for 4 oz. bottles 10351	48
No. 10415 screw caps for 8 oz. bottles 10351	48
No. 15070 funnels, diameter 100 mm.	2
No. 10480 bottle "Pyrex" for distilled water, capacity 2½ gallons	1
No. 11110 burners, size No. 3	2
No. 19770 tripod with concentric rings, size B	1
No. 19072 ring stand, size B	1
No. 12186 tubing clamps	4
No. 10979 test tube brushes	12
No. 10974 test tube brushes	12
No. 18200 rubber tubing, size C	6 feet
No. 12760 distilling apparatus (gas heated)	1
No. 10580 dropping bottles "TK," capacity 30 ml	6
No. 28305 microscope slides	1 gross

Supplies	*Quantity*
Bacto nutrient agar	2 lbs.
Bacto lactose broth	2 "
Bacto E.M.B. agar (Levine)	2 "
Bacto agar, granulated	1 "
Bacto M. R.-V. P. Medium (Clark and Lubs)	½ "
Bacto brilliant green bile medium	¼ "
Bacto formate ricinoleate broth	½ "
Bacto citrate medium (Koser)	¼ "
Ferric ammonium citrate	¼ "
Bacto peptone	½ "
Potassium acid phosphate	¼ "
Crystal violet	15 grams
Basic fuchsin	15 "
Iodine	20 "
Sodium bicarbonate	1 lb.
Sodium hydroxide (sticks)	½ lb.
Grain alcohol 95%	2 qts.
Acetone	1 pint

APPENDIX D

USEFUL INFORMATION

Convenient Equivalents

Hydraulics

1 second-foot (cubic foot per second) = 7.48 U. S. gallons per second = 448.8 gallons per minute = 646,272 gallons for one day.
1 second-foot for one year = 31,536,000 cubic feet.
1 second-foot for one day = 1.983 acre-feet (approximately 2.0).
100 U. S. gallons per minute = 144,000 gallons per day = 19,251 cubic feet per day.
1,000,000 U. S. gallons per day = 1.55 second-feet.
1,000,000 U. S. gallons = 3.07 acre-feet.
1,000,000 cubic feet = 22.95 acre-feet.
1 acre-foot = 43,560 cubic feet.
1 acre-foot = 325,850 gallons.
1 inch deep on one square mile = 2,323,200 cubic feet.
1 inch deep on 1 square mile = 0.0737 second-foot per year.
1 foot = 0.3048 meter.
1 mile = 1.60935 kilometers.
1 acre = 43,560 square feet.
1 acre = 209 feet square, nearly.
1 square mile = 2.59 square kilometers.
1 cubic foot = 0.0283 cubic meter.
1 cubic foot = 7.48 gallons.
1 cubic foot of water weighs 62.4 pounds.
1 cubic meter per minute = 0.5886 second-feet.

Power

1 horsepower = 550 foot-pounds per second.
1 horsepower = 746 watts.
1 horsepower = 1 second-foot of water falling 8.80 feet.
$1\frac{1}{3}$ horsepower is equal to about 1 kilowatt.
To calculate water power quickly: $\frac{\text{Second-feet} \times \text{fall in feet}}{11}$ = net horsepower on water wheel realizing 80 per cent of theoretical power.

Weights and Measures

1 milligram per liter = 1 part per million
1 kilogram = 2.205 pounds
1 pound = 453.6 grams
1 grain per gallon = 17.12 parts per million
1 part per million = 0.0584 grains per gallon
1 gallon = 231 cubic inches
1 cubic foot = 7.48 gallons
1 cubic foot of water = 62.4 pounds
1 gallon of water = 8.34 pounds
1 gallon = 3.785 liters

1 liter = 0.2642 gallons
1 liter = 1.057 quarts
1 liter = 61.02 cubic inches
1 inch = 2.54 centimeters
1 centimeter = 0.3937 inches
1 cubic foot per second = 646,272 gallons per 24 hours
1 cubic foot per second = 449 gallons per minute
1,000,000 gallons per 24 hour = 1.547 cubic feet per second
1,000,000 gallons per 24 hour = 694 gallons per minute
1 part per million = 8.34 pounds per million gallons
1 pound per million gallons = 0.1199 part per million
1 acre = 43,560 square feet
1 gram = 15.432 grains
1 pound = 7,000 grains
1 meter = 39.37 inches
1 cubic centimeter = 0.0610 cubic inches
1 cubic inch = 16.387 cubic centimeters
1 quart = 0.946 liters
1 gram = 0.0353 ounces
1 ounce = 28.3495 grams
Centrigrade temperature = (Fahrenheit − 32) × 5/9
Fahrenheit temperature = (Centigrade × 9/5) + 32
= (Centigrade × 1.8) + 32

Miscellaneous Conversion Factors

Multiply	*by*	*To Obtain*
Acres	43,560	Square feet
"	0.0015625	Square miles
"	4840	Square yards
Barrels—oil	42	Gallons—oil
" —cement	376	Pounds—cement
Bags or sacks—cement	94	Pounds—cement
Cubic feet	28,320	Cubic centimeters
" "	1,728	Cubic inches
" "	0.02832	Cubic meters
" "	0.03704	Cubic yards
" "	7.48052	Gallons (U. S.)
" "	28.32	Liters
" "	59.84	Pints (liq.)
" "	29.92	Quarts (liq.)
" " /minute	472.0	Cubic cms./sec.
" " / "	0.1247	Gallons/sec.
" " / "	0.4720	Liters/sec.
" " / "	62.43	Pounds of water/min.
" " /second	0.646317	Million gals./day
" " / "	448.831	Gallons/min.
Cubic inches	16.39	Cubic centimeters
" "	0.0005787	Cubic feet
" "	0.00001639	Cubic meters

Multiply	*by*	*To Obtain*
Cubic inches	0.00002143	Cubic yards
“ “	0.004329	Gallons
“ “	0.01639	Liters
“ “	0.3463	Pints (liq.)
“ “	0.01732	Quarts (liq.)
Cubic Yards	764,600	Cubic centimeters
“ “	27	Cubic feet
“ “	46,656	Cubic inches
“ “	0.7646	Cubic meters
“ “	202.0	Gallons
“ “	764.6	Liters
“ “	1616	Pints (liq.)
“ “	807.9	Quarts (liq.)
Degrees (angle)	60'	Minutes
“ “	0.01745	Radians
“ “	3600	Seconds
Degrees/sec.	0.1745	Radians/sec.
“ “	0.1667	Revolutions/min.
“ “	0.002778	Revolutions/sec.
Feet	30.48	Centimeters
“	12	Inches
“	0.3048	Meters
“	1/3	Yards
Feet of Water	0.02950	Atmospheres
“ “ “	0.8826	Inches of mercury
“ “ “	304.8	Kgs./sq. meter
“ “ “	62.43	Lbs./sq. foot
“ “ “	0.4335	Lbs./sq. inch
Gallons	3785	Cubic centimeters
“	0.1337	Cubic feet
“	231	Cubic inches
“	0.003785	Cubic meters
“	0.004951	Cubic yards
“	3.785	Liters
“	8	Pints (liq.)
“	4	Quarts (liq.)
“ , Imperial	1.20095	U. S. Gallon
“ , U. S.	0.83267	Imperial gallons
“ water	8.3453	Pounds of water
“ /min.	0.002228	Cubic feet/sec.
“ “	0.06308	Liters/sec.
“ “	8.0208	Cu. ft./hr.
“ “	$\frac{8.0208}{\text{Area (sq. ft.)}}$	Overflow rate (ft./hr.)
“ water/min.	6.0086	Tons water/24 hrs.
Grains/U.S. gal.	17.118	Parts/million
“ “ “	142.86	Lbs./million gal.

Multiply	*by*	*To Obtain*
Grains Imp. gal.	14.254	Parts/million
Grams	0.03527	Ounces
"	0.03215	Ounces (troy)
"	0.002205	Pounds
Horse power	42.44	B.T. Units/min.
" "	33,000	Foot-lbs./min.
" "	550	Foot-lbs./sec.
" "	1.014	Horse power (metric)
" "	10.70	Kg.-calories/min.
" "	0.7457	Kilowatts
" " (boiler)	33,479	B.T.U./hr.
" " "	9.803	Kilowatts
Inches	2.540	Centimeters
Inches of mercury	0.03342	Atmospheres
" " "	1.133	Feet of water
" " "	345.3	Kgs./sq. meter
" " "	70.73	Lbs./sq. ft.
" " "	0.4912	Lbs./sq. inch
Inches of water	0.002458	Atmospheres
" " "	0.07355	Inches of mercury
" " "	25.40	Kgs./sq. meter
" " "	0.5781	Ounces/sq. inch
" " "	5.202	Lbs./sq. foot
" " "	0.3613	Lbs./sq. inch
Liters	1000	Cubic centimeters
"	0.03531	Cubic feet
"	61.02	Cubic inches
"	0.001	Cubic meters
"	0.001308	Cubic yards
"	0.2642	Gallons
"	2.113	Pints (liq.)
"	1.057	Quarts (liq.)
Liters/min.	0.0005886	Cubic ft./sec.
" "	0.004403	Gals./sec.
Miles	160,900	Centimeters
"	5280	Feet
"	1.609	Kilometers
"	1760	Yards
Pounds	16	Ounces
"	256	Drams
"	7000	Grains
"	0.0005	Tons (short)
"	453.5924	Grams
"	1.21528	Pounds (troy)
"	14.5833	Ounces (troy)
Pounds of water	0.01602	Cubic feet
" " "	27.68	Cubic inches

Multiply	*by*	*To Obtain*
Pounds of water	0.1198	Gallons
Pounds of water/min.	0.000267	Cubic ft./sec.
Quarts (dry)	67.20	Cubic inches
Quarts (liq.)	57.75	Cubic inches
Quires	25	Sheets
Reams	500	Sheets
Square feet	0.00002296	Acres
“ “	929.0	Square centimeters
“ “	144	Square inches
“ “	0.09290	Square meters
“ “	0.00000003587	Square miles
“ “	1/9	Square yards
Square inches	6.452	Square centimeters
“ “	0.006944	Square feet
“ “	645.2	Square millimeters
Square miles	640	Acres
“ “	27,880,000	Square feet
“ “	2.590	Square kilometers
“ “	3,098,000	Square yards
Square yards	0.0002066	Acres
“ “	9	Square feet
“ “	0.8361	Square meters
“ “	0.0000003228	Square miles
Temp. (°C.) + 273	1	Abs. temp. (°C.)
“ “ + 17.78	1.8	Temp. (°F.)
Temp. (°F.) + 460	1	Abs. temp. (°F.)
“ “ − 32	5/9	Temp. (°C.)
Tons (short)	2,000	Pounds
“ “	32,000	Ounces
“ “	907.18486	Kilograms
“ “	2430.56	Pounds (troy)
“ “	0.89287	Tons (long)
“ “	29,166.66	Ounces (troy)
“ “	0.90718	Tons (metric)
Tons of water/24 hrs.	83.333	Pounds water/hour
“ “ “ “ “	0.16643	Gallons/min.
“ “ “ “ “	1.3349	Cu. ft./hr.
Yards	91.44	Centimeters
“	3	Feet
“	36	Inches
“	0.9144	Meters

APPENDIX E

USEFUL PUBLICATIONS

(Adapted from *Journal American Water Works Association*, January, 1937.)

LIST NO. 1—FOR MANAGERS AND OPERATORS OF SMALLER WATER WORKS

Books	*Publishers*	*Authors*
Water Works Practice Manual of the A. W. W. A.	Williams & Wilkins Baltimore, Md.	Various
The Operation of Water Filtration Plants (F)	N. C. State Dept. Health, Raleigh, N. C.	
Water Supply Control (F)	N. Y. State Dept. Health, Albany, N. Y.	Cox
Water Works Handbook	McGraw-Hill Book Co., New York City	Flinn, Weston & Bogert
Water Supply & Sewerage	McGraw-Hill Book Co., New York City	Steel
Water Purification Control	Williams & Wilkins, Baltimore, Md.	Hopkins
Standard Methods of Water Analysis	American Public Health Association, New York City	
Analysis of Water and Sewage	McGraw-Hill Book Co., New York City	Theroux, Eldridge & Mallmann
Water Purification	McGraw-Hill Book Co., New York City	Ellms
Manual of the American Steel & Wire Co., Water Purification (F)	American Steel & Wire Co., Chicago, Ill.	Brown
Use of Copper Sulfate in Control of Microscopic Organisms (F)	Nichols Copper Co., New York City	Hale
Technical Bulletins on Chlorination (F)	Wallace & Tiernan Co., Newark, N. J.	Various
Reprints of Articles on Chlorine and Its Application (F)	The Chlorine Institute, New York City	Various
Hydraulic Tables	John Wiley & Sons, New York City	Williams & Hazen
Cameron Hydraulic Data (F)	Ingersoll-Rand Co., Phillipsburg, N. J.	
Standard Schedule for Grading Cities and Towns (F)	National Board of Fire Underwriters, New York City	
Fire Engine Tests and Fire Stream Tables (F)	National Board of Fire Underwriters, New York City	
Handbook on Fire Protection	D. Van Nostrand Co., New York City	Crosby, Fiske & Forster

Books	*Publishers*	*Authors*
Plumber's Handbook	McGraw-Hill Book Co., New York City	Dibble
Handbook of Cast Iron Pipe (F)	Cast Iron Pipe Research Assn., Chicago, Ill.	
Examination of Water	John Wiley & Sons, New York City	Mason & Buswell
Civil Engineering Handbook	McGraw-Hill Book Co., New York City	Urquhart
General Engineering Handbook	McGraw-Hill Book Co., New York City	O'Rourke
Lefax—Data Sheets for Loose Leaf Note Books	Lefax, Inc., Philadelphia, Pa.	Various
Lime—Its Use in Water and Sewage Treatment (F)	National Lime Assn., Washington, D. C.	
Water Supply & Treatment (F)	National Lime Assn., Washington, D. C.	Hoover
A. B. C. of Hydrogen Ion Control (F)	LaMotte Company, Baltimore, Md.	
Modern pH Control (F)	W. A. Taylor Co., Baltimore, Md.	
Water Supply Engineering	McGraw-Hill Book Co., New York City	Babbitt & Doland
Plane Surveying	John Wiley & Sons, New York City	Tracey
Water Works and Sewerage Reference and Data Book	Gillette Publishing Co., Chicago, Ill.	
Water Well Standards (F)	State Health Dept., Austin, Texas	Cohen
Chemical Characteristics of Texas Well Waters (F)	State Health Dept., Austin, Texas	Cohen

(F) Available as free publications.

JOURNALS AND MAGAZINES

Journal American Water Works Association. Published 29 W. 39th St., New York City

Water Works Engineering. Published 24 West 40th St., New York City

Water Works and Sewerage. Published by Gillette Publishing Co., Daily News Building, Chicago, Ill.

LIST NO. 2—FOR MANAGERS, CHEMISTS, AND OPERATORS OF LARGE WATER WORKS

(In addition to List No. 1 for smaller works)

Books	*Publishers*	*Authors*
Fresh Water Biology	John Wiley & Sons, New York City	Ward & Whipple
Fresh Water Algae	McGraw-Hill Book Co., New York City	Smith

Books	*Publishers*	*Authors*
Elements of Water Bacteriology	John Wiley & Sons, New York City	Prescott & Winslow
Industrial Water Supplies	Ohio Geological Survey, Columbus, O.	Foulk
The Determination of H. Ions	Williams & Wilkins Co., Baltimore, Md.	Clark
pH and Its Practical Application	Williams & Wilkins Co., Baltimore, Md.	LaMotte, Kenney & Reed
Microscopy of Drinking Water	John Wiley & Sons, New York City	Whipple, Fair & Whipple
Elimination of Tastes and Odors in Water	McGraw-Hill Book Co., New York City	Baylis
Boiler Feedwater Purification	McGraw-Hill Book Co., New York City	Powell
Chemistry of Water and Sewage Treatment	Chemical Catalog Co., New York City	Buswell
Water Borne Typhoid Fever Outbreaks	Williams & Wilkins Co., Baltimore, Md.	Wolman & Gorman
Textbook of Bacteriology	Appleton and Co., New York City	Hiss & Zinsser
Water Supply Paper 274	U. S. Geological Survey, Washington, D. C.	Stabler
Corrosion: Causes and Prevention	McGraw-Hill Book Co., New York City	Speller
Studies of Efficiency of Water Filtration Processes	American Public Health Assn., New York City	
Handbook of Hydraulics	McGraw-Hill Book Co., New York City	King
Concrete Engineers' Handbook	McGraw-Hill Book Co., New York City	Hool & Johnson
Pocket Companion (F)	Carnegie Steel Corp., New York City	
Handbook of Pumps (F)	Worthington Pump Co., Harrison, N. J.	
Business Law for Engineers	McGraw-Hill Book Co., New York City	Allen
Mechanical Engineers' Handbook	John Wiley & Sons, New York City	Kent
Hydraulics	McGraw-Hill Book Co., New York City	Schoder & Dawson
Guiding Principles of Public Service Regulations (3 Vols.)	Public Utilities Reports Inc., Rochester, N. Y.	Spurr
Theory and Practice of Public Utility Valuation	McGraw-Hill Book Co., New York City	Maltbie
Public Utility Rates	McGraw-Hill Book Co., New York City	Barker

(F) Available as free publications.

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